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ORIGIN OF THE EMERY DEPOSITS NEAR PEEKSKILL, NEW YORK*

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ABSTRACT

Several theories of origin have been proposed for the emery deposits associated with the Cortlandt series of basic plutonics which lie south and east of Peekskill, New York. These are: (1) magmatic segregation; (2) absorption (assimilation) of aluminous sedimentary material (Manhattan schist); and (3) contact-metamorphism, under which two different stages of development have been considered—(a) hydrothermal contact-metamorphism; and (b) deposition in marginally solidified endomorphosed norite and exomorphosed schist by emanations released from the still-liquid portions of the magma.

Detailed field and petrologic studies of the emery have been made at Emery Hill, where the principal deposits are located. New evidence disclosed objections to the earlier theories and led to the formulation of a revised theory of genesis. The emery deposits are believed to be contact-metamorphic (pyrometasomatic) in origin, but were formed at a much earlier stage than previously thought. They are believed to have been formed by emanations that were released by the magma during intrusion and these emanations passed through the country rock (Manhattan schist) only a short distance in advance of the magma. Thus, the formation of emery took place during the early liquid-magmatic stage of the basic Cortlandt intrusives.

Detailed descriptions of the emery, the rock types, and their relations are given. Reference is made to usage of the terms "hornfels" and "endomorphism" because of their significance to a study of the emery deposits.

INTRODUCTION

One of the few commercial emery deposits in America is associated with the complex post-Ordovician Cortlandt series of basic plutonics south and east of Peekskill, New York. Several theories of origin have been proposed for the deposits. In brief, these are: (1) magmatic segregation; (2) absorption (assimilation) of aluminous sedimentary material; and (3) contact-metamorphism, under which two different stages of development have been considered. Additional information, disclosed by the writer's studies of the emery deposits, requires a modified theory of origin which is presented in this paper.

A historical review of the literature shows that Williams[1] suggested (1887) that the emery deposits were due to magmatic segregation, but a year later, following a more complete petrographic study of the Cortlandt series,[2] he favored contact-metamorphism.[3] Rogers,[4] as a result of areal and petrographic studies (1911) favored the theory of the absorption of sedimentary material. In his opinion, the absorption of aluminous sedimentary xenoliths or wall rock (Manhattan schist) formed aluminous segregations in the magma which crystallized to form emery. He made a strong point of the fact that experiments on artificial production of corundum by Morozewicz[5] supported his conclusion. Berkey and Rice[6] and Bowen[7] closely followed Rogers' ideas. Larsen[8] (1928) revived Williams' concept of contact-metamorphic origin, specifically favoring a hydrothermal phase. Two years later, Gillson and Kania[9] studied the emery deposits in the northeast corner of the Cortlandt series and concluded that they were contact-metamorphic but "were formed by gaseous or liquid emanations from the magma reservoir, which passed upward through the already solid border of the igneous mass, and into the schist, depositing the ore minerals in both endomorphic and exomorphic zones."

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[1] Williams, G. H., Norites of the Cortlandt series: *Am. Jour. Sci.*, Series 3, vol. **33**, p. 194, 1887.

Field and petrologic studies by the writer lead him to believe that the emery deposits near Peekskill are contact-metamorphic in origin, but were formed at a much earlier stage than previously thought. The emery is believed to have been formed by emanations that were released by the magma during intrusion and which essentially passed through the country rock (Manhattan schist) a short distance in advance of the magma.

The study of the problem covered one field season and numerous subsequent trips to the district. A topographic map of the principal emery producing area (Plate I) was made on the scale of 200 feet to the inch with a five foot contour interval, and a detailed geologic map (Plate

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[2] Williams, G. H., Peridotites of the Cortlandt series: *Am. Jour. Sci.*, Series 3, vol. **31**, p. 26, 1886.

Williams, G. H., Gabbros and diorites of the Cortlandt series: *Am. Jour. Sci.*, Series 3, vol. **35**, p. 438, 1888.

[3] Williams, G. H., Contact metamorphism produced in the adjoining mica schist and limestone by the rocks of the Cortlandt series: *Am. Jour. Sci.*, Series 3, vol. **36**, p. 268, 1888.

[4] Rogers, G. S., Geology of the Cortlandt series and its emery deposits: *Annals New York Acad. Sci.*, vol. **21**, pp. 11–86, 1911.

[5] Morozewicz, J., Experiment. Untersuchungen über d. Bildung d. Mineralien im Magma: *Tschermak's min., und pet. Mitt.*, vol. **18**, pp. 1–90 and pp. 105–240, 1898.

[6] Berkey, C. P., and Rice, Marion, Geology of West Point quadrangle: *New York State Museum Bull.*, Nos. 225–226, p. 90, 1919.

[7] Bowen, N. L., The behavior of inclusions in igneous magmas: *Jour. Geology*, vol. **30**, pp. 550–560, 1922.

[8] Larsen, E. S., A hydrothermal origin of corundum and albitite bodies: *Economic Geology*, vol. **23**, p. 429, 1928.

[9] Gillson. J. L., and Kania, J. E. A., Genesis of the emery deposits near Peekskill, New York: *Economic Geology*, vol. **25**, pp. 506–527, 1930.

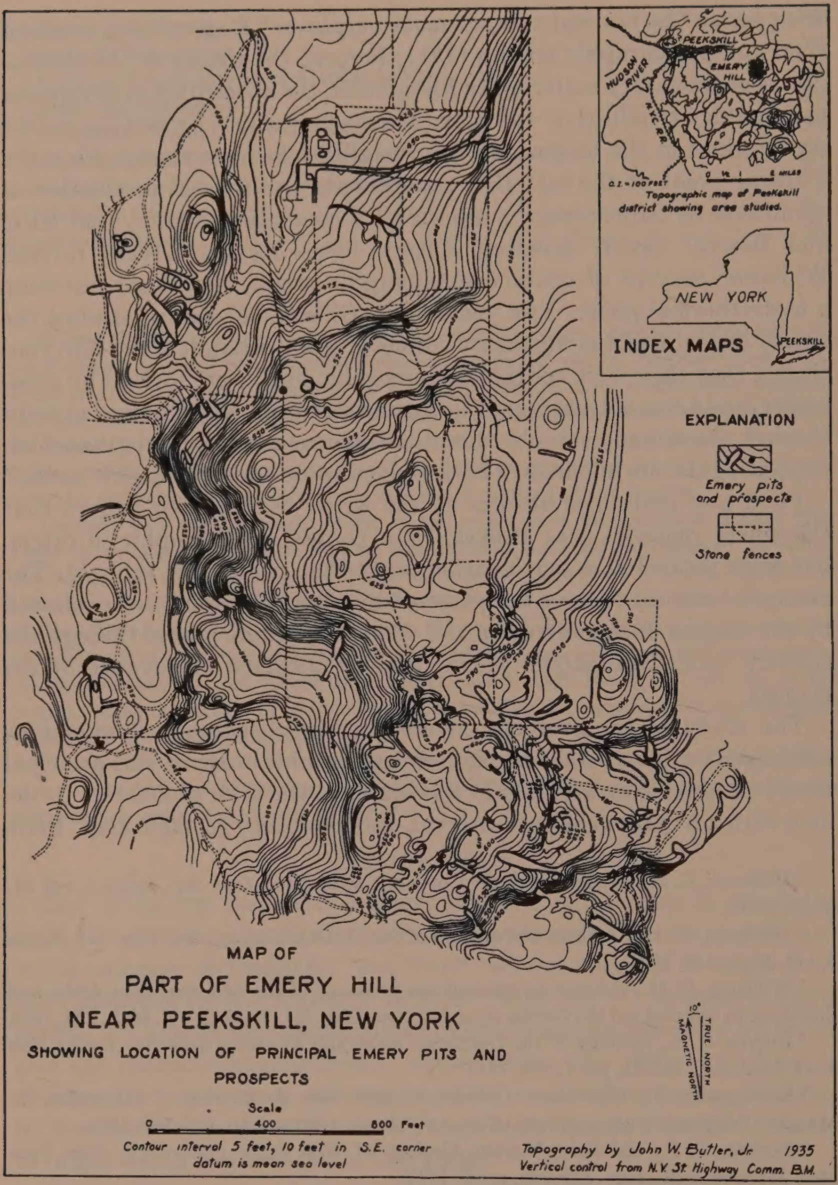

PLATE I

II) was plotted on this base. The area studied includes 54 major emery pits and 55 prospects. Many specimens were collected and more than a hundred of these were selected for thin-section and polished surface studies.

FIELD RELATIONSHIPS

GENERAL STATEMENT

The emery deposits are associated with the complex Cortlandt series of basic igneous rocks which was intruded into the tightly folded Manhattan schist—Inwood marble series of southeastern New York. The Cortlandt series has an areal extent of between 25 and 30 square miles, and crops out in an ovate east-west area which transects the north-northeast regional strike of the metamorphics. Manhattan schist surrounds the series except for three-quarters of a mile on the northeast, where Peekskill granite is mapped adjacent, and two and a half miles of the southern boundary, where Inwood marble has been intruded. Xenoliths of schist and marble are included in the Cortlandt plutonics. The commercial deposits of emery (a mixture of pleonaste, corundum, and iron ores) occur as pods and lenses associated with the exomorphosed schist and an endomorphosed igneous rock in the pyroxenite areas of the Cortlandt series, a fact observed by Rogers, and by Gillson and Kania.

The Manhattan schist deserves special attention. Its aluminous character, and the fact that the alumina and the iron content increase in the exomorphosed schist progressively toward contacts with the igneous rock, form the basis for fundamental arguments in favor of the absorption theory of emery origin. Therefore, the study of mineralogical changes accompanying contact metamorphism of the schist is particularly significant. Discussions and conclusions favoring origins of emery by magmatic segregation or any stage of contact-metamorphism require a general understanding of the complex nature and relationships of the Cortlandt series. For these reasons, brief descriptions of the Manhattan schist and the Cortlandt series are given to serve as a background for observations to follow.

GEOLOGICAL FORMATIONS

Manhattan Schist

The average specimen of Manhattan schist is a quartz-mica schist, completely recrystallized, distinctly foliated, and dominantly micaceous. Muscovite is the most characteristic mineral; biotite is common. Feldspar is found in many specimens, andesine being the most common variety, though the range from orthoclase to labradorite is reported.[10] Garnet is the chief accessory mineral and often carries inclusions such as quartz, magnetite, and biotite. Other accessory minerals include tourmaline, staurolite, sillimanite, apatite, kyanite, zircon, zoisite, rutile, pyrite, and magnetite, which are found alone or together in a variety of combinations and proportions. Pegmatitic injections and quartz veins are plentiful in certain areas and in those places the schist generally becomes feldspathic. It intergrades at the contact with the underlying dolomitic Inwood marble.

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[10] Fettke, Chas., The Manhattan schist of southeastern New York State and its associated igneous rocks: *Annals New York Acad. Sci.*, vol. **23**, pp. 193–260, 1914.

Cortlandt Series

Dana[11] recognized the unique quality of the Cortlandt series and named it for Cortlandt township in which it occurs. Other areas of similar lithology are at Stony Point, across the Hudson River, and at Rosetown, New York,[12] a mile west. Connecticut[13] contains two areas of similar rocks; one about 5 miles west of Litchfield, and the other north of Danbury.

The complexity and quality of the series changes rapidly from outcrop to outcrop and even within the range of a single exposure. Many rock types exist; Rogers described granite, syenite, sodalite syenite, diorite, gabbro, several varieties of norite and pyroxenite, peridotite, and hornblende. Dike rocks include aplite, pegmatite, dacite porphyry, dioritic and gabbroic dikes, hornblendite, and serpentine (altered peridotite).

Rogers has shown that noritic rocks constitute the bulk of the Cortlandt series and are centrally located with respect to related rock types; pyroxenitic and peridotitic rocks form the eastern third of the area and the southwestern portion contains the largest diorite area, numerous schist and marble xenoliths, and pyroxenite and peridotite rock types which crop out near the Hudson River. It is significant to the present problem that the noritic rocks solidified after the pyroxenite types had developed. The Peekskill granite, which according to Berkey[14] is related to the series because of mutual high soda content, forms a separate mass to the northeast of the basic area; no mutual field relations with the basic Cortlandt rocks have been observed.

ROCK TYPES OF EMERY HILL

General Statement

Three principal emery producing districts have been found within the Cortlandt series: (1) the southwestern part of the igneous area in the vicinity of Crugers, (2) the southeastern part in the vicinity of Salt Hill, and (3) Emery Hill (also known as Garnet Hill) in the northeastern part, where the detailed investigations set forth in this paper were made. The first was least important and the last was by far the most important producer. All three districts are associated with areas of pyroxenite, as

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[11] Dana, James Dwight, Geological relations of the limestone belts of Westchester Co., New York: *Am. Jour. Sci.*, Series 3, vol. **20**, p. 194, 1880.

[12] Kemp, J. F., On the Rosetown extension of the Cortlandt series: *Am. Jour. Sci.*, Series 3, vol. **36**, p. 247, 1888.

[13] Hobbs, W. H., On two new occurrences of the "Cortlandt Series" of rocks within the State of Connecticut: *Festschrift zum siebzigsten Geburtstage von Harry Rosenbusch*, E. Schweizerbartsche Verlagsbuchhandlung, Stuttgart. p. 25, **(1906)**

[14] Berkey, C. P., The acid extreme of the Cortlandt series: *Science*, vol. **28**, p. 575, 1908.

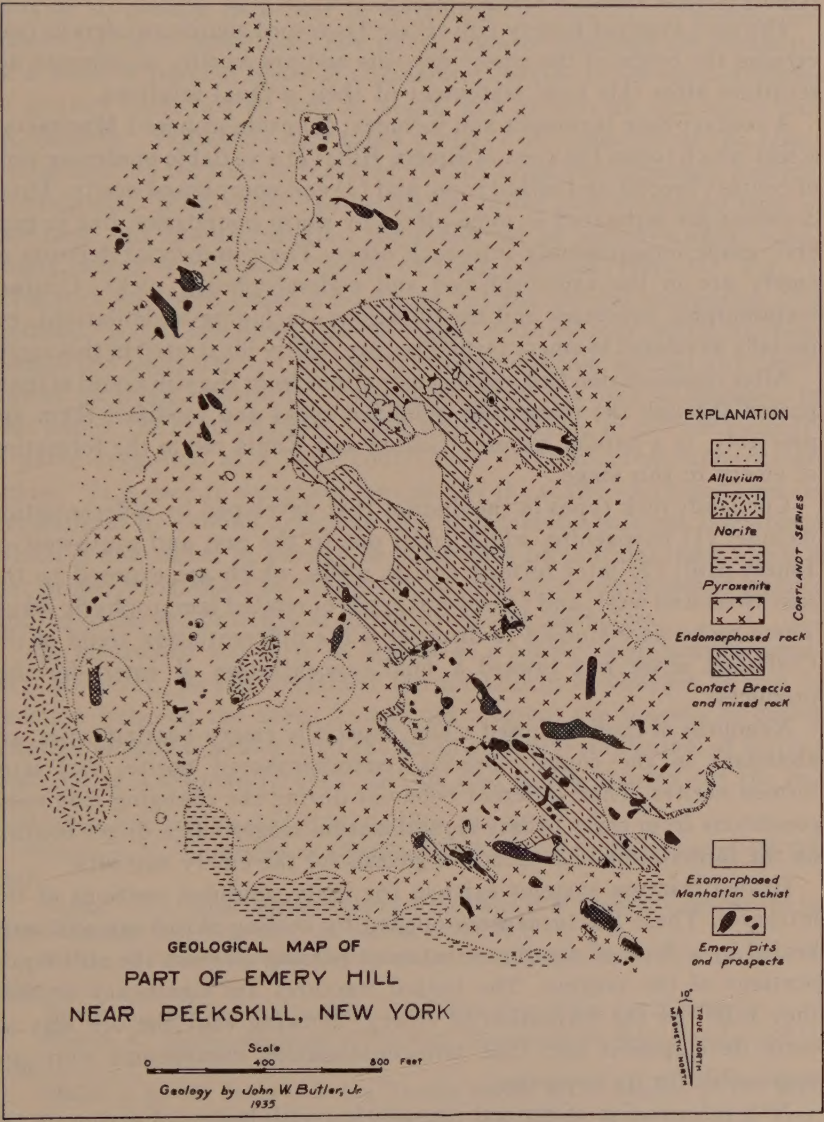

PLATE II

delineated by Rogers, and are near the borders of the intrusive series.

Emery Hill, where the chief emery deposits are found, lies nearly two and a half miles east of Peekskill. The Crompond Road from the village passes directly north of it. The hill attains an altitude of 650 feet and is a conspicuous topographic feature in its vicinity where the maximum relief averages about 225 feet.

The rock types of Emery Hill (Plate II) record significant details concerning the origin of the emery deposits and are worthy of separate description after this brief statement of their mutual relations.

A contact zone is present and includes: (1) exomorphosed Manhattan schist which forms the crest of Emery Hill; (2) a variable bordering zone of contact breccia and mixed rock; and (3) endomorphosed norite. These divisions are separated in some places by sharp boundaries, but in general, grade imperceptibly into each other. The commercial deposits of emery are in the exomorphosed and endomorphosed rocks. Contact metamorphic processes and modifications (including assimilation), especially as related to emery formation, are clearly illustrated in this zone.

After consolidation had begun, emanations from the still liquid magma passed through the marginally solidified rocks and modified them appreciably, in a patchy manner. Gillson and Kania relate the formation of emery to this stage.

Cortlandt rock types in the district that developed by differentiation include: (1) pyroxenite, which crops out to the east and southwest of Emery Hill; (2) later formed noritic rocks, which are exposed to the southwest and west; and (3) several types of related lamprophyric dikes. These rocks were studied to discover if the differentiation trend of the Cortlandt series was toward a final concentration of emery-forming products.

Xenoliths of exomorphosed schist, especially emery-bearing types, are abundant in the contact breccia, endomorphosed norite, and later formed norites. Their different behavior during the changing magmatic conditions from early to late crystallization stages has a direct bearing on the formulation of a theory of genesis for the emery deposits.

Healed fracture systems exist in the early solidified portions of the intrusive. These fractures were opened by cooling shrinkage and were healed by a flood of deuteric substances passing off from the still liquid portions of the magma. The healed fractures are significant because they followed the formation of emery, showing that the ore was an early development and that late-consolidation emanations were not responsible for its formation.

New information of general interest, but with indirect bearing on the problem, has been included in some of the detailed descriptions of rock types in order to present a more complete picture of the geological relations.

CONTACT ZONE ROCK TYPES

Exomorphosed Schist or Metaschist

Contact-metamorphism has changed the schist to a tough, dense, grayish to pinkish rock that is variable in its texture, structure, and mineralogical composition. The finest textured portions are composed of a mass of parallel fibers of sillimanite; coarser types contain blades of kyanite exceeding an inch in length, and garnets an inch and a half in diameter. Sillimanite-rich types preserve the foliation of the schist better than do the coarser-textured, patchy types rich in garnet, kyanite, or staurolite. Differential weathering has pitted and roughened most of the rock and has accentuated the preserved or pseudomorphic schistosity, which is generally obscure on fresh surfaces (Plate III, Fig. 1). This rock has been called a hornfels[15] but the general conception of a hornfels[16] is that of a dense, fine- to sugary-textured rock, which has been completely recrystallized by contact-metamorphism so that any cleavage or incipient schistosity of the parent rock has been obliterated. In this paper, the exomorphosed schist will be referred to as "metaschist," a name suggested as a loose contraction of "contact-metamorphosed schist." It is used to designate that part of the schist which has been recrystallized by contact action so that it contains a mineral assemblage which is new either in variety or in obvious proportions, and which is not properly classified as "hornfels" because of its coarseness of texture and/or preserved or newly acquired structural characters.

The metaschist was early recognized as a contact-metamorphic product. However, Bowen explained the mineralogical changes as due to reaction between the schist and liquid magma, the process involving solution of soluble oxides from the schist and recrystallization of surplus material as a sillimanitic rock. Gillson and Kania pointed out the im-

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[15] Gillson, J. L., and Kania, J. E. A., *Op. cit.*, p. 517, 1930.

[16] Grout, F. F., Petrography and Petrology. McGraw-Hill Book Co., Inc., p. 370–372, **1932.**

Grout, F. F., Contact metamorphism of the slates of Minnesota by granite and by gabbro magmas: *Bull. Geol. Soc. Am.*, vol. **44,** p. 999, 1933.

Harker, A., Metamorphism. Methuen & Co., Ltd., London, pp. 5, 23, 35, 39, 97, 333. **1932.**

Harker, A., Petrology for Students. Cambridge Univ. Press, p. 271. **1919.**

Holmes, A., The Nomenclature of Petrology. Thomas Murby & Co., London, p. 119. **1928.**

Shand, S. J., The Study of Rocks. Thomas Murby & Co., London, p. 179. **1931.**

Tyrrell, G. W., The Principles of Petrology. E. P. Dutton & Co., Inc., New York, pp. 271, 272, 291, 295, 305. **1929.**

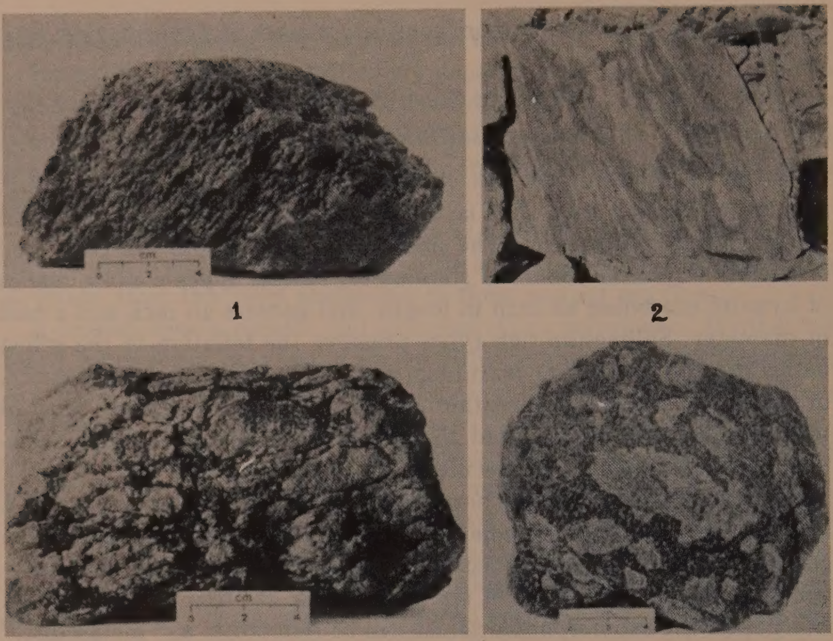

Plate III

Plate III, Fig. 1. Sillimanitic type of exomorphosed schist, showing the preserved, or "pseudomorphic" schistosity which is accentuated by differential weathering.

Plate III, Fig. 2. Banded feldspathic emery from southern part of Emery Hill area. Note how emery (dark) tends to follow the contortions of the former foliation; it also tends to cut some of the feldspathic streaks. A zone of healed fractures cuts the block parallel to its lower side.

Plate III, Fig. 3. Specimen B-9. Contact breccia with parallel, elongate, corroded inclusions. The intruding Cortlandt magma apparently filtered into the rock along structural weaknesses such as the foliation.

Plate III, Fig. 4. Specimen 151. Contact breccia facies in which sufficient magma had been intruded to make the mass mobile and destroy the parallel alignment of the tiny xenoliths before final solidification. The igneous rock is more feldspathic than in the facies illustrated in Plate III, Fig. 3. Note the narrow feldspathic border which is conspicuously developed around some xenoliths.

possibility of such a process modifying the schist "tens of feet from the contacts." Emanations released during the course of intrusion and solidification of the Cortlandt magma were undoubtedly largely responsible for the aureole of exomorphosed schist.

The mineral assemblage in the metaschist is large, and detailed paragenetic relations are obscure; they seem to vary throughout. This is because the paths of emanations escaping from the magma were not uniformly distributed throughout the schist and they tended to shift from time to time, so that the mineral products of their activity are irregular in distribution and concentration. In general, it can be said that garnet (almandite?), some biotite, and some minor accessories such as zircon, are relics of the schist and are products of regional metamorphism. Some feldspar and quartz may have the same history.

Sillimanite, kyanite, staurolite, cordierite, biotite, chlorite, sapphirine, chloritoid, and possibly some garnet and feldspar are products of neomineralization or recrystallization caused by contact-metamorphism. Amphibole, some biotite, andesine and sodic labradorite (extinction on (100) albite twin lamellae = 30°), tourmaline, allanite, and possibly quartz have been introduced from the Cortlandt magma.

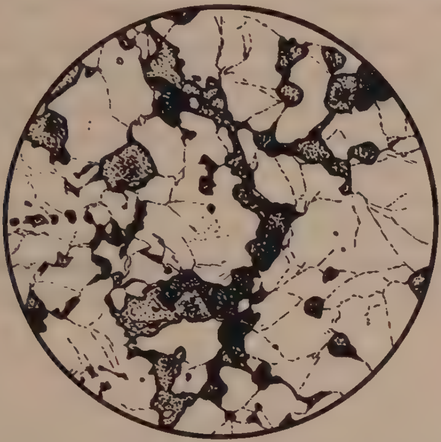

FIG. 1. Illustration of the penetrating and introduced character of emery minerals in the exomorphosed schist. Pleonaste, some högbomite (both stippled), and iron ores (black) have been introduced along fractures in garnet (white) which is practically the only relic mineral of the Manhattan schist that is left. A later developed fracturing is also present in the garnet.

Finally, pleonaste, högbomite, corundum, iron ores, some biotite, and an associated low birefringent amphibole with optical properties approaching pargasite belong to the stage of emery development. The iron ores cut everything, except in several cases where amphibole appeared last. In places, intergrowths of amphibole and spinel are found between plagioclase and emery. Emery minerals have been introduced into old fractures in the garnet (Fig. 1).

The dissemination of emery minerals throughout the metaschist cannot be explained by the absorption theory. The ore must have been formed or introduced by magmatic emanations at some time during the process of exomorphism.

Contact Breccia

A variable zone of contact breccia and associated mixed rock (schist and pyroxenite, or norite) exists between the metaschist and the endomorphosed norite. The contact breccia is crowded with tiny corrosion-rounded inclusions (Plate III, Figs. 3, 4) and in many places near the contact, the xenoliths are often spaced so closely that they simulate a conglomerate. The contact breccia, although limited in extent, is important because it presents the opportunity to study the gradual changes xenoliths undergo after being immersed in the basic magma. Petrologic observations relative to the development of emery are stated under the subject of xenoliths.

Outcrops of the contact breccia on Emery Hill exhibit features suggesting that many inclusions were formed not so much by shattering of the metaschist as by gradual separation and isolation of fragments by a seeping and permeating magma. The magma accomplished this by filtering into the rock along foliation and other structures (Plate III, Fig. 3). The rounding and reduction of the boundaries of fragments by magmatic corrosion or absorption occurred with the continuation of the process. If sufficient magma was forced between inclusions, the whole became mobile as a unit. Continued influx of magma diluted the contact breccia and ultimately formed rock facies in which xenoliths are widely scattered.

In this zone intrusion evidently took place in pulsations because rock crowded with xenoliths may be found intruded by a dike or mass of rock containing fewer inclusions, and this in turn may be cut by other igneous intrusions containing still fewer xenoliths. The boundaries are sharp or gradational. Where sharp, xenoliths in the earlier formed rock may be transected. Dikes composed entirely of igneous rock may intrude everything.

In some places, magmatic aggression proceeded faster into the metaschist than in adjacent areas; as a result, some larger blocks of metaschist gradually became surrounded by contact breccia and magma and were thus ultimately engulfed in the advancing magma by this stoping process.

Endomorphosed Rock

Many variations in appearance and composition of the endomorphosed rock are expectable. Syntexis developed a variable rock, which was further modified after solidification, by emanations passing through it from the still-liquid magma below. A short description can be only a generalization.

The most impressive facies of the endomorphosed rock is a dark-colored porphyritic type in which the phenocrysts are large poikilitic black hornblende or, rarely, biotite, set in a much finer-textured groundmass of feldspar and pyroxene. Many of the glistening cleavage faces of hornblende are 2.0 cm. across. Extreme widths of 9.0 cm. are found elsewhere in the series. They stand out in relief on some weathered surfaces. Biotite phenocrysts are smaller. The groundmass minerals in these varieties rarely exceed one millimeter in diameter, but generally become larger as the phenocrysts become smaller. Some portions of the rock are quite micaceous. As a rule, the igneous rock adjacent to xenoliths or emery pits is fine- to medium-grained, and feldspathic to the point of having a "salt and pepper" appearance. Outcrops have a dark, dirty appearance. Rogers[17] and Gillson and Kania[18] made special reference to this type.

In addition to hornblende, augite, pigeonite, hypersthene, enstatite and biotite, the variable endomorphosed rock contains apatite, some epidote, zoisite, and unabsorbed garnets held over from assimilated schist. Quartz is common. There is generally no more than 15 per cent feldspar in the basic varieties of rock. It is labradorite and more sodic varieties, and many of these have been corroded or partly replaced by more sodic feldspar, brought in by passing emanations. In such cases, the poikilitic hornblende is also altered to uralite and a low birefringent amphibole.

The poikilitic hornblende deserves attention because of its relation to the contact zone. Various writers[19] have considered it to be a late crystallizing orthotectic mineral, or deuteric in origin. It replaces, embays, corrodes, and includes pyroxenes, and doubtless is of deuteric origin in the most limited sense of the term. However, it not only occupies pyroxene replacement areas, but has filled interstitial spaces as well.

The writer suggests that the igneous poikilitic hornblende in the endomorphosed zone is an index of that zone because the mineral developed under the special conditions prevailing there, and its substance would have crystallized as pyroxene under conditions prevailing farther within the magma chamber. The fact that the formation of hornblende was retarded may be attributed, in part, to lag of the magma in responding to the newer conditions, among which were lower temperatures and the increasing amounts of mineralizers present. Kennedy's[20] recent study of factors influencing the development of hornblende or pyroxene in igneous rocks supports this hypothesis, as does earlier work by Allen, Wright, and Clement.[21] A brief field examination in other parts of the Cortlandt series confirmed the view that the poikilitic hornblende may be one of the indicators of the endomorphosed zone.

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[17] Rogers, G. S., *Op. cit.*[4], pp. 35, 70, 73, 1911.

[18] Gillson, J. L., and Kania, J. E. A., *Op. cit.*[9], pp. 513–517, 1930.

[19] Williams, G. H., Peridotites of the Cortlandt series: *Am. Jour. Sci.*, Series 3, vol. **31**, p. 30, 1886.
Rogers, G. S., *Op. cit.*[4], pp. 36, 43, 1911
Gillson, J. L., and Kania, J. E. A., *Op. cit.*[9], p. 511, 1930.
Howe, Ernest, Sulphide-bearing rocks from Litchfield, Conn.: *Economic Geology*, vol. **10**, p. 333, 1915.

The criterion used by Gillson and Kania to distinguish endomorphosed rock from their fresh "mela-norite," which also contained poikilitic hornblende, was that the post-consolidation emanations had modified the former. The changes described are similar to those associated with deuteric effects. They also considered the presence of hydrothermal or pneumatolytic quartz as indicative of the process of endomorphism. They pictured the process as taking place after a marginal zone of the intrusive had solidified. Residual emanations, which passed up from the magma chamber, through the crystallized margins and into the country rock, brought about these modifications and made the consolidated border zone an "endomorphosed rock."

Such a procession of events is evident, but it is only fair to question the application of the term "endomorphism"[22] to post-consolidation

[20] Kennedy, W. Q., The influence of chemical factors on the crystallization of hornblende in igneous rocks: *Mineral. Mag.*, vol. **24,** pp. 203–207, 1935.

[21] Allen, E. T., Wright, F. E., and Clement, J. K., Minerals of the composition $MgSiO_3$; A case of tetramorphism: *Am. Jour. Sci.*, Series 4, vol. **22,** pp. 385–438, 1906.

[22] This confusion concerning the significance of the term "endomorphism" has crept into the literature since the time Spurr, Garry and Fenner [Spurr, J. E., Garry, G. H., and Fenner, C. N., A contact metamorphic ore deposit, the Dolores Mine at Matehuala, San Luis Potosi, Mexico: *Economic Geology*, vol. **7,** pp. 471–474, 1912] set forth their important observations on contact metamorphism at the Dolores Mine, San Luis Potosi, Mexico. Subsequent comments by Spurr [Spurr, J. E., Theory of ore deposition: *Economic Geology*, vol. **7,** p. 485, 1912], Umpleby [Umpleby, J. B., Geology and ore deposits of the Mackay Region, Idaho: *U. S. Geol. Survey*, *Professional Paper* **97,** p. 65, 1917], Eckermann [Eckermann, Harry von, The rocks and contact minerals of the Mansjö Mountains: *Geol. Fören. Förh.*, p. 343, **1922**], and Gillson [Gillson, J. L., Contact metamorphism of the rocks in the Pend Oreille District, Northern Idaho: *U. S. Geol. Survey*, *Professional Paper* **158-F,** 1929], carried this trend of thought down to Gillson and Kania's application of the same in the Emery Hill district. However, Umpleby did distinguish between an earlier "contact metamorphism" and a later post-consolidation "contact metasomatism."

Holmes [Holmes, A., *The Nomenclature of Petrology*. Thos. Murby & Co., London, p. 90, 1928], following Fournet's original definition [*Bull. Geol. Soc. de France*, vol. **4,** series 2, p. 243, 1847], defines "endomorphism" as follows:

"The modification produced in an igneous rock due to the partial or complete absorption (assimilation) of portions of rocks invaded by its magma; a phase of contact-metamorphism in which attention is directed to the changes suffered by the intrusion instead of to those produced in the invaded formations."

To the above possible modifications can be added contact chilling effects such as would affect texture of the intrusive or the kind of minerals crystallizing during consolidation.

modification of an igneous rock by its own final consolidation residues. Endomorphism (contact-metamorphism within the intrusive) is established in the literature as signifying the modifications in an igneous rock which are influenced by the country rock. The process ceases when the marginal portions of an intrusive have become inactive and solidified. Thus, post-consolidation modifications of an igneous rock by its own final consolidation residues are strictly magmatic effects and do not result from any influence of the country rock.

Close study failed to disclose a zone of "endomorphosed norite" between fresh "mela-norite" and the schist contact, as Gillson and Kania intimate. The "mela-norite," or fresh norite, is often found closer to the contact than is the "endomorphosed norite." Field relations and petrologic study revealed that the "mela-norite" does not represent a distinct and later-formed rock which was in places intruded into the endomorphosed rock, but it is part of the marginal solidified zone, or endomorphic rock. The apparent incompatible distribution of "mela-norite" and "endomorphosed norite" is explained by the fact that the paths followed by the modifying emanations through the solidified border zone were selective and irregular; consequently, modifications are distributed in a patchy manner throughout that zone. It is believed that the modifications attributed to endomorphism by Gillson and Kania are properly classified as later developments in the endomorphosed rock.

DIFFERENTIATED ROCK TYPES

Pyroxenite

Pyroxenite rock types crop out east and southeast of Emery Hill. Fresh specimens are dark, coarse- to fine-grained, massive, granitoid rock. They may weather reddish or grayish.

Both monoclinic and orthorhombic subhedral and anhedral pyroxenes are the essential constituents. Augite is most plentiful and has simple and polysynthetic twinning parallel to (100). A strongly pleochroic monoclinic pyroxene (X=pink, Y=light pink, Z=greenish) is present in subordinate amounts. It has a small optic angle, is optically positive, and its birefringence is closer to that of augite than to that of hypersthene. The optical data suggest that it is pigeonite. Hypersthene is present in varying amounts, in some places subordinate to pigeonite. Many of the larger pyroxenes have wavy extinction, and tiny needle-like inclusions and schiller structures are plentiful.

Minor amounts of deep-brown, strongly pleochroic, biotite occur as final consolidation replacements or alterations of pyroxene.

These additions follow the thought in the last clause of Holmes' definition. This understanding of endomorphism will be used through the paper.

The amount of olivine varies in these rocks. It is optically positive; irregular in outline; and its fractures are generally filled with serpentine.

Some small patchy sericitic aggregates mark last crystallizing areas in this rock. The centers of these areas are usually medium basic plagioclase, seldom larger than 0.3 mm. in diameter. The lingering residual liquids have clearly altered the surrounding pyroxene or olivine in the immediate vicinity to irregular aggregates of magnetite, biotite, serpentine, sericite (?), and uralite. Sometimes carbonate is present. No orthotectic or deuteric development of spinel or corundum was observed.

Norite

With increase of feldspar the pyroxenite rock types grade into noritic types, which crop out on the southwestern side of Emery Hill and westward. These rocks are medium- to coarse-grained and dark gray, though much lighter on the weathered surface than are the pyroxenitic types. Schlieren, flaser, and other mineral orientation structures are well developed. Many xenoliths are present. Emery-bearing types are common, and autoliths of pyroxenite indicate that norite crystallized after the pyroxenitic rock types. The noritic magma was still liquid when the margins of the intrusive had solidified and so released emanations which passed through the already solidified rock types.

The mineral components include varying amounts of plagioclase, ranging from medium labradorite (extinction on albite twin lamellae normal to (010) zone$=35°$) to oligoclase, pyroxene in the form of augite, pigeonite and hypersthene, and biotite. Some pale blue-green pleochroic uralite has developed from the pyroxene. Ilmenite and apatite are characteristic accessories of the noritic rocks. The former is mostly associated with the ferromagnesian minerals, and cuts across them.

Myrmekite and quartz-biotite-symplektite are scattered throughout the rocks. These final-consolidation products cut into earlier-formed minerals. They are deuteric in the most limited sense of the term and show that while consolidating, the norite followed the normal differentiation trend from ferromagnesian and lime-rich minerals to sodic and silicic minerals. No indications observed in the composite mineral assemblage suggest that the norite magma differentiated toward an unusual alumina-rich residue, as should be the case if the emery minerals were deposited by escaping "gaseous or liquid emanations" passing through two rocks as different as the endomorphosed norite and the metaschist.

Dikes

Dark, fine- to medium-textured lamprophyric dikes, up to 6 inches wide, are present, especially in the foliated norite. They resemble kersantite and spessartite varieties. Field relations indicate that they had formed as units and began intruding the norite while it was still somewhat plastic, the intrusion continuing after the norite had solidified, or at least behaved as a solidified crystalline rock.

Some similar, but much more feldspathic, dikes are found cutting emery in several of the emery pits, especially those west of Emery Hill. The relationships will be described later.

Dikes rich in feldspar, and containing hornblende crystals up to 4.0 or 5.0 cm. long, are found in the southeastern portion of the mapped area on the hillside, at about altitude 540 feet. They penetrate the contact breccia and adjacent igneous rock.

Small myrmekite and myrmekite-like patches are common in the dikes. Quartz and oligoclase are abundant as final-crystallization and replacing minerals. It is significant that the final-consolidation products are silicic and alkalic minerals. The differentiation which developed the magmas of the dikes apparently did not develop a concentration of emery mineral constituents. No corundum or spinel is present except in xenoliths.

Emery-Bearing Xenoliths

Small xenoliths from the contact breccia, endomorphosed rock, and various portions of the noritic rock types were examined with special reference to the genesis of the emery minerals. The contact breccia has been described. The endomorphosed rock and norite contain many small xenoliths which include: (1) rare quartzose inclusions, which probably are remnants of quartz veins or pegmatites originally in the schist (a green chloritic or uralitic border surrounds them); (2) feldspathic inclusions, usually containing small amounts of disseminated emery minerals; and (3) emery-rich inclusions, with which we are now concerned.

The small emery-rich inclusions in the endomorphosed rock have ovate, or lens-shaped forms, or are tabular masses up to a foot or two long and nearly an inch wide. Many xenoliths have an internal laminated structure due to the varied concentration of component minerals. Large pyroxene or biotite crystals are found in some xenoliths. A feldspar border, one to two millimeters thick, surrounds the inclusions. Between this feldspathic border and the coarser-grained endomorphosed rock is a variable zone, up to an inch wide, of "salt and pepper" type of feldspathic norite. The "salt and pepper" zone calls to mind Bowen's[23] deductions concerning the precipitation of calcic plagioclase and hypersthene during the advance stages of assimilation. Read[24] recently described patches of this character in the norite of the Haddo House District, Aberdeenshire, and interpreted them as of xenolithic origin.

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[23] Bowen, N. L., *Op. cit.*, 1922.

In places, tabular emery masses and many other small inclusions are grouped crudely parallel in the endomorphosed rock, in a manner suggesting that they form a zone of pinching and swelling veins of emery. However, closer inspection discloses that a few of the tabular masses are abruptly terminated at one end, showing that they are not veins, but have been broken from a larger mass and are xenoliths.

Many of the emery-rich xenoliths are believed to be unassimilated emery-bearing remnants of larger masses.

Petrologic study suggests that the conditions important in the development of the emery were so closely related to the conditions prevailing during the immersion of the xenoliths in the liquid magma that, in many instances, it is difficult to judge whether the surrounding magma caused emery minerals to develop, or whether it caused them to be disaggregated and destroyed. However, wherever the surrounding magma was rich in mineralizers, or flooded by emanations after solidification, the emery minerals tended to be destroyed.

The disaggregation of emery is observed in many small inclusions from the contact breccia. The tiny xenoliths are mostly masses of medium basic plagioclase anhedra through which the emery is disseminated. The ore has separated into tiny aggregates composed of various combinations of corundum, iron ore, and spinel, with a few projecting fibers of sillimanite and biotite, and possibly a clinging fragment of associated low birefringent amphibole. The intruded basic igneous rock has been uralitized and modified by magmatic emanations.

Earlier stages of the process are exhibited. Tiny xenoliths in specimen No. 151 (Plate III, Fig. 4), from just west of the crest of Emery Hill, contain several granular aggregates of corundum, metallic minerals, and feldspar, all gathered in the shape of corundum crystals (Plate IV, Fig. 1). Corundum grains in the aggregates have various optical orientations and are embayed so that they have ramifying forms. It is apparent that these granular aggregates are not synneusis clusters, or corundum crystals in the process of development. They are interpreted as an arrested early stage in the disintegration or disaggregation of corundum crystals.

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[24] Read, H. H., The gabbros and associated xenolithic complexes of the Haddo House District, Aberdeenshire: *Quart. Jour. Geol. Soc. London*, vol. **91**, part 4, pp. 608, 609, 620–622, 629–630, 1935.

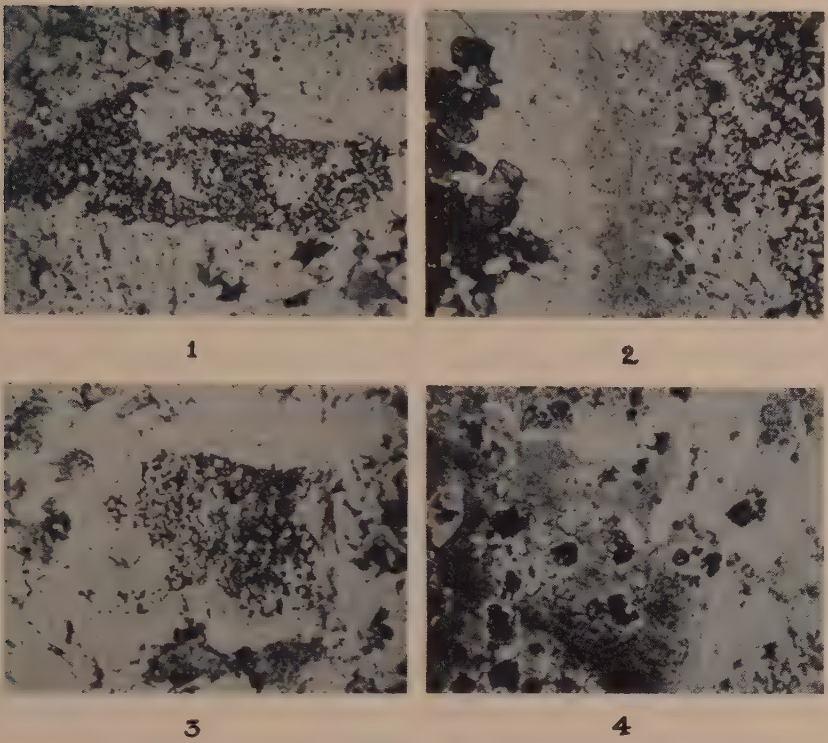

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PLATE IV

Plate IV, Fig. 1. Photomicrograph (×16) illustrating what are believed to be corundum crystals in an early state of disaggregation and destruction, as found in small xenoliths in the contact breccia (Spec. 151). The aggregates in the shapes of corundum crystals (cf. Plate V, Fig. 3) consist of corroded corundum aggregates, iron ores, and feldspar. Emery minerals are disseminated generally throughout the feldspathic inclusion shown.

Plate IV, Fig. 2. Photomicrograph (×18) illustrating the zoning which is developed in xenoliths by magmatic immersion. Dark minerals on the left are pyrozene of the endomorphosed rock; to the right is a narrow border of plagioclase; then, a section of the sericitic aureole around the inclusion; and farthest to the right is the main body of the inclusion which consists of large feldspar and biotite crystals through which pleonaste and iron ores (both black) are disseminated.

Plate IV, Fig. 3. Photomicrograph (×17) illustrating a microscopic xenolith of exomorphosed schist in norite from southwest of Emery Hill. The inclusion has become so small that the former aureole of micaceous material now forms the entire goundmass. Emery minerals are black and have ramifying forms. Some zoisite and epidote, and meshes of sillimanite fibers are present.

Plate IV, Fig. 4. Photomicrograph (×17) illustrating pleonaste altered by magmatic emanations. The pleonaste was disseminated through a xenolith composed principally of plagioclase and biotite. Outlines of former spinel grains are preserved by a metallic dust and a mesh of sillimanite fibers, biotite and possibly cordierite or feldspar. A few cores of unaltered pleonaste remain. Larger biotite crystals and the sillimanite fibers developed during the process of spinel alteration. The endomorphic rock surrounding this xenolith was also modified by deuteric emanations.

The process of liquid-magmatic modification of xenoliths has also developed a zoning in many while they were being corroded or absorbed. The zones consist of a narrow outer border of tiny plagioclase crystals, which gives place inwardly to a sericitic aureole. The interiors of the inclusions generally are composed of larger plagioclase and brown biotite, which contain scattered individuals of spinel, up to 0.2 mm. in width, in a poikilitic structure (Plate IV, Fig. 2). This modification process seems to continue until the inclusions are reduced to microscopic size (Plate IV, Fig. 3) and finally disappear.

Passing emanations alter the emery minerals. Spinel, especially, is changed to a residue of metallic dust and a mesh of sillimanite fibers, biotite, and possibly cordierite or feldspar (Plate IV, Fig. 4). Thus, emery minerals seem to be developed in xenoliths by the earliest stages of igneous metamorphism and are destroyed by the later magmatic processes.

HEALED FRACTURES

One of the most persistent features in the western pyroxenite area, and one which has not been hitherto described, is the multitude of light-green vein-like lines, or narrow bands, that are spread like an irregular network over the outcrops. These "vein-like" features appear to represent a system of cooling-shrinkage fractures in early solidified igneous rock, which have been healed by a flood of deuteric emanations passing off from the yet-liquid magma chamber. The development and healing of the fractures took place after solidification of the endomorphosed rock, pyroxenite, some norite and lamprophyres, and, most important of all, *after formation of the emery.* It is especially significant from the standpoint of genesis that: (1) emery is cut by the healed fractures, thus showing that the ore had formed before the healed fractures developed; that (2) the fractures were healed with deuteric substances; and that (3) the deuteric substances tended to *destroy*, rather than to *develop* emery, so are eliminated as agents of emery formation.

The following petrographic descriptions of the healed fractures are given to show the deuteric nature of the healing emanations and how they modified, rather than developed emery.

In the pyroxenite and endomorphosed rock, the healed fractures may stand up in slight relief on weathered surfaces. The green bands vary in width from hair-lines to rare maximum widths of 3¾ inches. Most of them are less than an inch wide. A narrow central portion is white deuteric feldspar that has healed the fractures. The first deuteric crystals to form were sodic labradorite. Cores of that mineral were surrounded, embayed, transected, and replaced by progressively more sodic plagio-

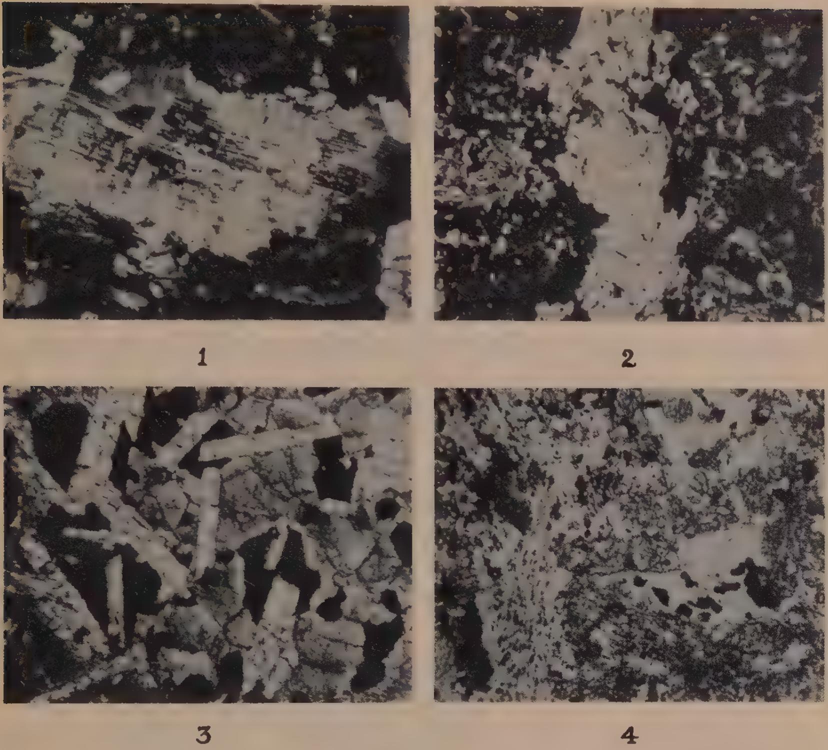

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PLATE V

Plate V, Fig. 1. Photomicrograph (×18, crossed nicols) illustrating deuteric plagioclase which heals many fractures and joints in the district. It is believed that the healed fracture systems were opened by cooling-shrinkage in early solidified Cortlandt rocks. The cores are sodic labradorite (extinction on albite twin lamellae normal to (100) zone=30°) and the corroding and replacing feldspar is progressively more sodic up to oligoclase.

Plate V, Fig. 2. Photomicrograph (×18) illustrating a healed fracture cutting emery. The fracture is filled with corundophyllite instead of the usual deuteric feldspar which is present where these fractures cut the igneous rock. Emery minerals have been cut through, altered, and replaced. All the spinel nearby has been changed to dusty black metallic matter. Some clouded corundum crystals and chlorite patches remain. Iron ores are black.

Plate V, Fig. 3. Photomicrograph (×33) illustrating gangue-free emery from west side of Emery Hill. Corundum (white) is elongated in basal plates, pleonaste (gray) is the most plentiful component, and iron ores (black—include: magnetite, specularite, and ilmenite) are generally in close association with, or surround the corundum.

Plate V, Fig. 4. Photomicrograph (×18) of a specimen from the large "keystone" emery block which remains in Strang's "Long Pit" to show that the ore is a mineralized exomorphosed schist xenolith and not a vein. The ore has been modified by magmatic emanations which passed through the early solidified endomorphosed rock from the still liquid magma. Pseudomorphic schistosity is preserved by unaltered sillimanite in the left side of the picture. Several broken and disaggregated crystals of corundum are in the center and top of the picture. Staurolite is in the lower center and right; light gray groundmess is chlorite. The black mineral is ilmenite.

clase up to oligoclase (Plate V, Fig. 1). Cloudy remnants of older feldspars exhibit deformation fractures and bent twin lamellae, and some of these stress structures are preserved by replacing feldspar. Accessory minerals are apatite, epidote, and zoisite. Apatite is most abundant and forms synneusis clusters.

The green megascopic appearance of the healed fractures is caused by wide borders of uralitized and chloritized wall rock. This alteration of the ferromagnesian minerals was effected by the soda-bearing deuteric emanations that passed along the fractures and penetrated their walls.

Wherever the healed fractures cross emery they contract to 1.0 mm. and less in width and corundophyllite with optical properties between protochlorite and ripidolite is present instead of feldspar (Plate V, Fig. 2). The emery is altered on either side of the "veinlets" for a distance of about 2.5 mm. Corundum is more resistant to alteration than the spinel. Corundum-rich emery is changed to dusty aggregates of magnetite and corundum. Spinel-rich emery is similarly altered, but also contains a few tiny blue corundum crystals or larger corundum crystals in which only small spots are a deep blue. Spinel is completely altered to dusty aggregates and small chlorite patches are disseminated throughout.

EMERY DEPOSITS

General Statement

Emery pits and prospects in the northeastern part of the Cortlandt series are distributed mainly along the east and west flanks of Emery Hill and across the southern part of the crest (Plate I); glacial overburden conceals the rocks underlying the smooth north slope. Only one pit has recently been in part time operation. The others evidently were abandoned shortly after the close of the World War period of activity. As pointed out by previous writers, the emery deposits form irregular pods, lenses, and vein-like masses, both in the metaschist and in the endomorphosed rock. However, the larger pits, with few exceptions, are narrow, long, and deep. Strang's "Long Pit" (Fig. 2) is a specific example. It is over 130 feet long, 10 to 30 feet wide, and was excavated to an approximate depth of 25 feet. A number of pits are larger than this, especially in the matter of depth, one in the southeastern part of the Emery Hill district being 80 feet deep. The elongate shape is generally characteristic whether the pits are in endomorphosed rock or in metaschist.

MINERALOGY AND STRUCTURE OF THE EMERY

Pure Peekskill emery in the hand specimen is a heavy, massive, black, fine-textured aggregate. In some samples, corundum crystals (most of them white, but in some specimens pink or blue) are large enough to be distinguished. The ore is tough and breaks with an irregular fracture. Pure emery is rare, and the presence of gangue minerals of different kinds or proportions modify its appearance. Gangue minerals characteristic of the metaschist tend to preserve a pseudoschistosity or banded

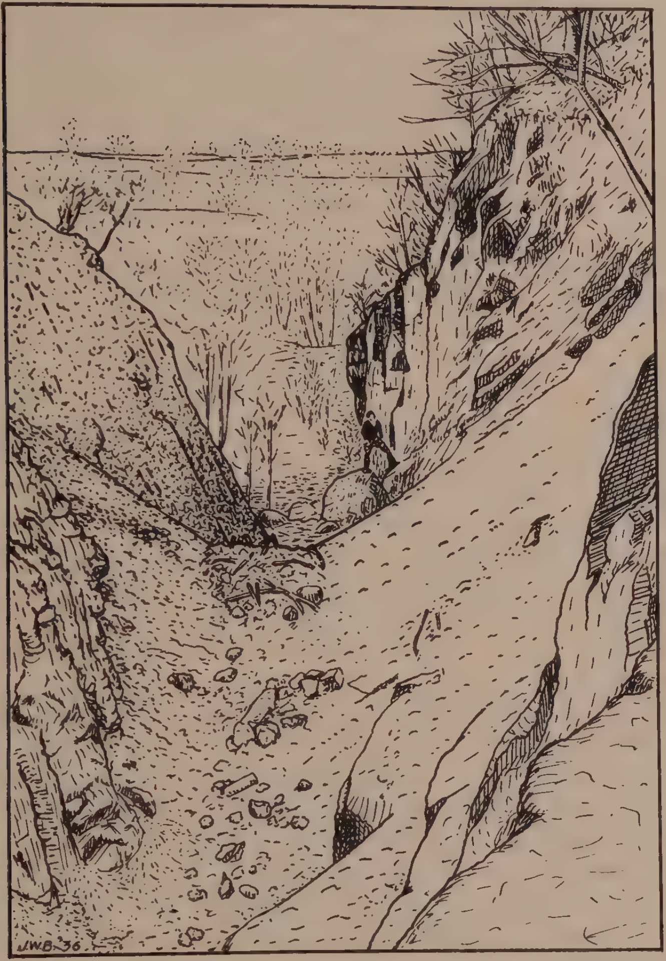

FIG. 2. Strang's "Long Pit," looking northwest. An illustration of the elongate shape of many major emery pits.

structure in the ore and lighten its color to gray. Emery containing abundant garnet has a pinkish cast, and quartz and feldspar give the ore a streaked appearance.

Under the microscope, the Peekskill ore shows varying proportions of pleonaste, corundum, and the metallic iron ores (Plate V, Fig. 3). Rogers' analyses[25] showed the spinel to be a magnesia-poor variety of pleonaste. It owes its abrasive quality to a hardness of 8, and is the principal emery mineral of the district. The metallic minerals include magnetite, specularite, and ilmenite. Corundum varies in amount; it may be absent, or it may displace pleonaste entirely. It is euhedral and is developed in elongated basal plates. In places, högbomite (hardness = 6.5) is associated with the spinel in minor amounts, especially where the emery is in metaschist.

The iron minerals were usually the last to form, filling interstices between spinel and corundum. The metallic minerals often bound the euhedral or subhedral corundum, as though the latter had influenced their precipitation. Some polished surfaces show that magnetite completed its development before ilmenite and specularite, both of which marginally replace it to a certain extent in places. Exsolution structures of these minerals in each other are common. There is some good dactylitic development of magnetite and ilmenite.

Gangue minerals vary according to the local geologic history. They include various combinations and proportions of sillimanite, garnet, biotite, cordierite, staurolite, kyanite, feldspar, amphibole, pyroxene, quartz, chlorite, and chloritoid (?). Apatite is not present as an associate of the iron ores, except under conditions in which it may be traced to adjacent norite.

The emery has a banded structure, which suggested to previous writers a relationship between the ore and the schist. This banding varies in width from a millimeter to several centimeters. It is especially noticeable in sillimanitic ore, in which the bands tend to be parallel to the pseudomorphic schistosity of the exomorphosed rock. Even in most specimens of pure emery the concentration of spinel, corundum, and metallic minerals varies enough to produce a noticeable laminated structure. Most of the corundum crystals are oriented more or less parallel to the banded structure.

Description of Emery Deposits

Most of the emery pits have wall rocks of both metaschist and igneous rock; a few are entirely in metaschist; and a few are entirely in igneous (endomorphosed) rock, though never farther than about 100 feet from xenoliths of metaschist. Important differences, significant enough to justify special consideration, exist between the emery deposits in metaschist and those in endomorphosed igneous rock.

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[25] Rogers, G. S., *Op. cit.*, p. 69, 1911. (Two analyses).

Emery Deposits in Metaschist

The few emery pits which are cut in metaschist are found in the southeastern portion of the area mapped (Plate II).

In sillimanite-rich types of metaschist, the ore has a pronounced banding usually parallel to the pseudomorphic schistosity. In patchy types of metaschist rich in garnet, kyanite, or staurolite, and in mixed rock, the pseudomorphic foliation is less uniformly preserved, and emery has a sharp cross-cutting habit. Bordering zones of biotite and amphibole are characteristically associated with the latter deposits and are believed to have been developed by emanations accompanying those that introduced the emery. This association is not found when the emery deposits are entirely in igneous rock. Rogers observed the abundance of biotite in this section of the emery district, but he did not point out this interpretation of its significance and special relationship to the emery.

Syntectic igneous rock usually crops out close to deposits. Thus, the emery seems to have been formed or deposited by emanations from an igneous source passing through the mixed rock and into the exomorphosed schist. The aluminous country rock apparently was a favorable body for "fixing" or retaining the emery components of the emanations and may have contributed material, at one point or another, which helped to establish the aluminous character of the ore ultimately deposited.

An example of cross-cutting emery in the patchy type of metaschist is in the excavation at about 450 feet altitude, in the southeast corner of the area. The emery occurs near the bottom of the high northwest wall and is entirely in metaschist. Irregular apophyses extend upward and outward from the main mass. The contacts are sharp. Above the emery, for a varying width, approaching and exceeding three feet, is a zone of coarse-grained biotite and associated dark greenish-black hornblende. A similar, but less extensive, zone exists below the emery. The wall rock has a "mixed" appearance and is essentially a garnetiferous, feldspathic metaschist. Contact-metamorphism has destroyed the old schistosity or modified it into patchy structures. The plagioclase is calcic andesine, deuterically modified by later-crystallizing more sodic plagioclase. Here and there, it is found in fractures of the garnet, as are, also, blue-green hornblende and a few scattered grains of staurolite. Ilmenite and magnetite are found together in a pronounced dactylitic structure. The eastern portion of the north wall is syntectic igneous rock.

The large pit at the west end of this same outcrop also has much mica associated with the emery. Garnets, surrounded here by the metallic-rich emery, have a conspicuous kelyphitic rim of chlorite. Much mica is also found at the pit in the southern portion of the map, altitude 600 feet. This deposit is in thoroughly mixed schist and igneous rock.

The banded character of the ore is well illustrated in the longest pit at the southern edge of the map. The pseudomorphic foliation strikes northwest and has a vertical dip. Mining has followed a narrow zone, between 15 and 20 feet wide, about 125 feet long, and about 50 feet deep. The banded sillimanitic emery ore passes to a banded emery-bearing sillimanitic metaschist at the margins of the pit.

Emery Deposits in Endomorphosed Rock

Emery deposits in the endomorphosed rock were found to be xenoliths of mineralized metaschist, rather than veins as has been suggested.[26] It is believed that geologic relations suggest that the emery was essentially developed before the xenoliths were engulfed by the magma. During magmatic immersion, the emery appears to have been less susceptible to absorption than was the metaschist, and sometimes only a residue of irregular-shaped masses of ore remain. In places, later deuteric emanations passed through the early solidified endomorphosed rock from the still-liquid portions of the magma chamber, and modified both the emery and the endomorphosed rock. Several of the deposits are cut by siliceous dikes of the Cortlandt series, containing minerals that exhibit deuteric modifications. Likewise, fracture systems, which opened by cooling shrinkage and were later healed with deuteric substances, cut the emery in some of the pits. Petrologic examination indicates that deuteric substances and late magmatic emanations modified or destroyed the emery rather than deposited it. These observations fail to agree with the theories that emery developed from emanations after marginal solidification of the intrusive, as suggested by Larsen and by Gillson and Kania.

Banded sillimanitic emery deposits are common in the endomorphosed rock. Such a structural arrangement is not a likely result of crystallization from a magma and seems logically explained only as the result of mineralizing emanations penetrating the metaschist along the preserved foliation. Thus, the structure of emery deposits presents significant evidence against the absorption theory of origin. These observations date the formation of emery close to (if not before) the earliest stages of Cortlandt intrusion. The criteria on which these conclusions are based are set forth below.

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[26] Gillson, J. L., and Kania, J. E. A., *Op. cit.*, p. 523, 1930.

The xenolithic nature of emery deposits in the endomorphosed rock, and characters which help to date the formation of the ore, are illustrated in Strang's "Long Pit" (Fig. 2) which is cut in the hillock at the northwest base of Emery Hill. The walls are endomorphosed rock of the poikilitic hornblende type and patches of emery still cling to them. Both emery and wall rock show deuteric modification and alteration by emanations. An undermined keystone-shaped block of ore remains in the southeast end of the long pit (Fig. 3). The general appearance of the deposit is suggestive of a large emery vein, but petrologic examination revealed that the ore is a modified xenolith of mineralized metaschist (Plate V, Fig. 4). Pseudomorphic schistosity characteristic of the metaschist is still preserved, especially where sillimanite needles have escaped alteration. Emanations developed a groundmass rich in chlorite. Corundum is disaggregated along partings and fractures, and is replaced, in part, by staurolite and chlorite. Staurolite is the most conspicuous mineral in the rock; its amount is surprisingly large. Masses of it interfinger with corundum or form either large (1.5 mm. by 0.5 mm.) solid or skeleton crystals. Cordierite is present; accessories are rutile, zircon, and tourmaline. Spongy ilmenite is the sole metallic mineral.

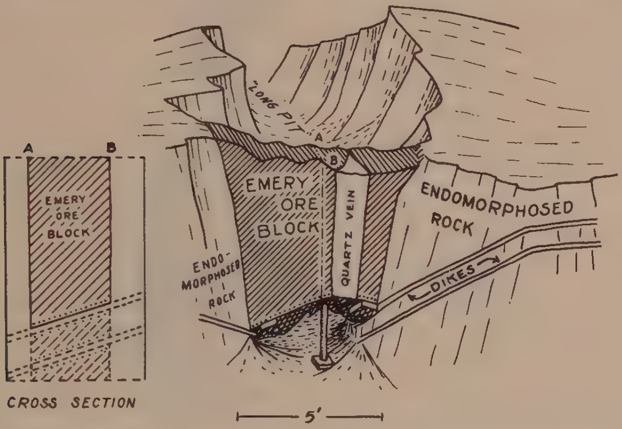

FIG. 3. Diagram to illustrate relationships between keystone block of emery ore and cross-cutting Cortlandt series dikes at the southeast end of Strang's "Long Pit."

A half-inch wide, northwest dipping dike cuts the present bottom of the block of emery. The fine-textured dike averages 23 per cent quartz, 63 per cent feldspar (sodic andesine to oligoclase) and the rest is hornblende and green biotite. Where it cuts the emery, the dike narrows to one-quarter of an inch in width, becomes more feldspathic, and develops chloritic borders. Deuteric effects were found in the dike.

"The cross-cutting vein" character of the emery in endomorphosed rock was pointed out by Gillson and Kania. They figured a specimen of ore-bearing norite from this vicinity, which showed a "vein" of emery extending from a larger mass of ore. The figure illustrated that "the emery occurs in the endomorphosed igneous rock as a sharply cross-cutting vein, not as a remnant of a partially absorbed inclusion of schist."[26]

Similar specimens have been collected by the writer, but close examination has always revealed a narrow border of feldspar surrounding the emery. This border is separated from coarser-textured endomorphosed rock by a narrow zone of medium-grained "salt and pepper" feldspathic endomorphosed rock. Identical feldspathic borders and zones are found surrounding undoubted xenoliths, as previously described. This suggests that the irregular ore masses, instead of being emery veins cutting previously formed endomorphosed rock, may be irregular masses of emery or emery-bearing rock which were caught up in magma that absorbed them in part and ultimately solidified around them.

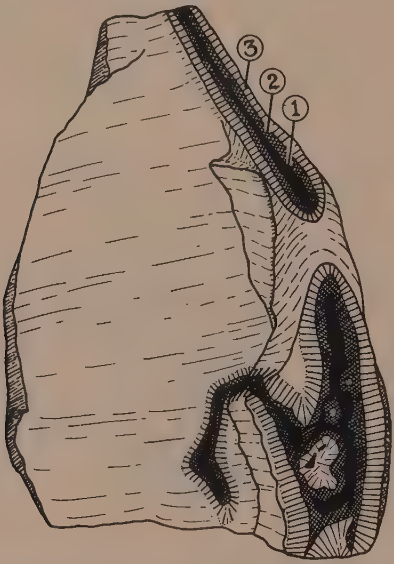

FIG. 4. Diagram illustrating modified xenoliths of emery-rich exomorphosed schist which imitate veins in endomorphosed rock. Specimen collected from wall of Strang's "Long Pit." Deuterically modified emery is separated from deuterically modified endomorphosed rock by a corundophyllite border. Microscopic examination revealed remnants and chlorite pseudomorphs of sillimanite and biotite in the emery. (1) is "fresh" emery, (2) is border of emory modified by igneous emanations, (3) is border of corundophyllite, all are enclosed by endomorphosed rock.

A small vein-like mass of emery in endomorphosed rock (Fig. 4), taken from the north wall of Strang's "Long Pit," is of special interest in this respect. Its irregular shape does not resemble the remnant of a xenolith engulfed in the noritic magma, but suggests agreement with Gillson and Kania's conclusion. However, close study reveals that a border of green corundophyllite separates the emery from the igneous rock. The peripheral portions of the emery "vein" have a dull black appearance, but the central portion is bright, fresh, shiny black. In thin-section, the dull-appearing outer border of emery is revealed as ore that has been altered in the same manner as emery modified by the deuteric emanations that travelled along the healed fracture "veins" through the ore (Plate V, Fig. 2). Some pseudomorphs of chlorite after sillimanite and biotite, both of which minerals are characteristic associates of emery deposits in metaschist, are present. A residue of sagenite preserves the shapes of biotite flakes in some places. In spite of the first impression that this specimen of emery is a vein with a cross-cutting relationship to the endomorphosed rock, one must conclude that the emery is a remnant of ore originally developed in metaschist which was later engulfed by the magma and partially absorbed and altered to its present state by the enveloping igneous substances.

The banded structure of emery parallel to the pseudomorphic schistosity of inclusions is illustrated in a significant prospect at the southwest base of Emery Hill, some 250 feet east of Strang's "Horseshoe Pit." The wall rock is endomorphosed norite containing numerous small xenoliths. The prospected material is a metaschist xenolith in which the pseudomorphic schistosity is exceedingly well preserved; a few small garnets are scattered through it. The emery is found in a number of bands, which are parallel to the structure, but are not abundant enough to make commerical ore of the block. A "salt and pepper" zone of endomorphosed norite surrounds the metaschist block, in the manner described as characteristic around smaller xenoliths.

The significant feature, however, is that the pseudomorphic schistosity is unmistakably transected by the sharp contact of the emery-bearing metaschist with the igneous rock. In some places, the pseudomorphic schistosity makes an angle of between 25 and 30 degrees with the contact. Some of the transected bands are emery. Crystallization of the emery in this structure from a magma, as suggested by the absorption theory of origin, is impossible. It is also definitely shown that the emery does not form cross-cutting veins through the endomorphosed rock and into the metaschist along certain favorable channels. The emery is restricted to the metaschist block, except for small xenoliths scattered about in the igneous rock.

The time of emery development in the above described xenolith essentially may have been either: (1) after the xenolith became immersed in the magma, in which case ore-developing emanations were drawn directly from the magma in contact, or (2) before the block of metaschist was engulfed in the magma, and while emery-developing emanations were penetrating the country rock.

The second hypothesis seems more reasonable because: (a) Elsewhere, emery is found in portions of the metaschist in proximity, but not necessarily immediately surrounded by, or in contact with, igneous rock; hence, contact with magma does not seem necessary to develop emery. (b) Some xenoliths of exomorphosed schist are found well within the igneous rock, so that they had ample opportunity to drain emery forming substances from the liquid magma; nevertheless, they do not contain much emery. (c) No concentrations of emery or emery-rich components were observed ponded in the igneous rock bordering the emery bands in metaschist, as might be the case if the rock solidified before the process of emery introduction had exhausted itself. (d) The emery in this block is in bands more widely separated than are the perceptible differences in schist or metaschist. It is difficult to explain why the magma should be so extremely selective when so close at hand. Such selectiveness seems more likely if the magmatic source were distant. In fact, emery ore in deposits with metaschist wall rocks shows closer spacing of emery bands than this xenolith does. (e) Both emery and metaschist bands are transected abruptly at the edge of the xenolith. (f) No continuous zone or margin of emery penetration was observed around the periphery of the metaschist block.

Formation of emery previous to immersion of xenoliths in the Cortlandt magma, in part at least, is illustrated on the west wall of the large emery pit, 80 feet north of Strang's "Long Pit." The endomorphosed rock cuts through an emery layer, 3½ inches wide, and includes fragments of the emery as pieces of an igneous breccia. The fragments are surrounded by feldspathic borders and zones of "salt and pepper" norite characteristic of xenoliths in the endomorphosed rock.

A narrow zone of disintegrating, crumbling rock usually surrounds emery deposits in the endomorphosed rock. So far as could be determined, this is largely due to a relative concentration of sulphides in the igneous rock neighboring the ore-bearing xenoliths. Sulphides are abundant enough so that weathering of them often yields conspicuous patches of hydrous iron sulphate. The chemical, and attendant physical, changes produced by weathering of the sulphides may account for the disintegration. The effects of dynamic action in the form of shearing and crushing around emery workings were pointed out by Rogers.

EVIDENCE OF STRUCTURAL CONTROL

A general consideration of the strikes and locations of the 54 major emery pits and the 55 smaller prospects in the district mapped (Plate I) suggests that mineralization might have been along several northwesterly-southeasterly striking zones rather than in random locations. The area was studied in an endeavor to determine whether or not a structural control actually existed and, if so, its cause. The map suggests that one possible zone of pits extends northwest from the southeast corner of the area. Another, less well defined, seems to extend southeasterly from the buildings on the Horowitz property to the crest of the hill. Several good-sized pits lie some distance east of the area mapped and would seem to fit with a projection of this zone if it were warped to strike between S. 65° E. and S. 75° E.

Strang's "Horseshoe Pit" and others in the southwestern portion of the map may lie in a northwest-southeast striking zone that crosses a small patch of swamp, and includes several small pits just beyond the southern edge of the area.

To test the existence and extent of these possible zones, their strikes were followed northwest and southeast, beyond the immediate area, but no conclusive evidence was found.

Several explanations may be advanced to account for what appears to be an alignment or structural control over the location of emery deposits. The "zones" may follow: (1) *lines of fracture or structural weakness;* (2) favorable *beds* in the metaschist; (3) *contacts* of metaschist and igneous rock; or (4) the *local strike* of the pseudomorphic schistosity in the metaschist. Lastly, (5) the "zones" may be only apparent, rather than real.

Lines of fracture or structural weakness have doubtful support as factors controlling emery deposition. To have been effective, they must have existed before intrusion of the Cortlandt series, because of the early date of emery mineralization. In that case, they would have been obliterated in the area occupied by the intrusive. Furthermore, the xenolithic nature of deposits in the igneous rock discounts the value of citing such pits in proving the existence of this, or any other, type of zone. Linear pits in the endomorphosed rock owe their shape to the original form of the emery-bearing xenoliths engulfed in the magma. Structural features in the metaschist are, thus, involved to whatever extent they guided developing the shapes of the xenoliths.

As for the second hypothesis, no distinctive beds have been found in the metaschist in units large enough to be traceable. Thus, field evidence discounts this possibility.

All emery deposits are not found at the contact of the igneous rock and metaschist, even though they are near the igneous rock; thus, the third hypothesis cannot be accepted as a generalization.

It has been shown that emery does follow the pseudomorphic schistosity in the metaschist, and that the ore shoots are parallel to this structure where it is well developed. However, this structure is not always well preserved, nor does it have a uniform strike throughout the area.

Careful analysis has led the writer to conclude that the zoning is more apparent than real, and that the chance location of mineralized xenoliths, some favorable contacts, and the strike of pseudomorphic schistosity have co-operated to suggest structural alignment.

ORIGIN OF THE EMERY

The theories of origin suggested for the emery deposits near Peekskill by previous writers include: (1) magmatic segregation; (2) absorption (assimilation) of aluminous country rock (Manhattan schist); and (3) contact-metamorphism, under which two different stages of development have been considered—(a) hydrothermal contact-metamorphism, and (b) deposition by magmatic emanations released after marginal consolidation of the Cortlandt plutonics was completed. The latter can be called a late-crystallization stage contact-metamorphic, or a "deuteric" contact-metamorphic theory of origin.

The present study of rock types and emery deposits in the Emery Hill district has revealed new evidence which indicates that the emery was developed earlier than was formerly believed, and, thus, a revised theory of origin is required. The possibility that emery was deposited previous to intrusion of the basic Cortlandt series is discussed, but it is concluded that deposition of the ore took place during intrusion of the Cortlandt plutonics, at an earlier stage than previously believed.

MAGMATIC SEGREGATION

In 1887, Williams[27] suggested magmatic segregation as the genesis of the emery. Although he changed his view in favor of contact-metamorphism the following year, his first conclusion was cited in the literature for a number of years. His earliest hypothesis is now given attention only on historical grounds. The fact that emery deposits are in exomorphosed schist rules out this hypothesis. Rogers[28] has presented other objections in greater detail.

ABSORPTION (ASSIMILATION) OF ALUMINOUS ROCK

In 1911, Rogers suggested that the emery was formed by absorption of aluminous Manhattan-schist xenoliths in the basic Cortlandt series magma, thereby developing a magma supersaturated in iron and alumina, "from which the emery would separate out according to the laws formulated by Morozewicz." Much of Rogers' argument was based on the artificial production of corundum, especially following the experiments of Morozewicz,[29] which showed that corundum, sillimanite, or cordierite will form in a melt, depending upon the variation in proportions of alumina, silica, magnesia, and iron oxide.

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[27] Williams, G. H., *Op. cit.*, 1887.

[28] Rogers, G. S., *Op. cit.*, p. 80, 1911.

Rogers recognized differences between the mineralogical features of the emery and the laboratory products. Nevertheless, he was disposed to believe that the emery was formed by reaction between magma and aluminous country rock, because the clay crucibles used by Morozewicz were attacked at a high temperature by melts rich in magnesia and poor in alumina and alkalis.

Berkey and Rice[30] followed Rogers' conclusions. Bowen[31] accepted this theory and presented a theoretical discussion of probable reactions which would account for certain mineralogical relationships.

In spite of such acceptance, the magmatic absorption theory has unsurmountable difficulties, chief among which is the fact that emery is found in the exomorphosed schist *removed from contact with the magma.* Nor does this theory explain the occurrence of emery in distinct narrow bands paralleling the pseudomorphic schistosity in the metaschist, even where the latter is found as xenoliths. The presence of quartzose streaks in the emery, whose minerals (corundum and spinel) are silica-poor, is incompatible with the theory of assimilation. Furthermore, a study of emery-bearing xenoliths, from different points within the series, demonstrates that the ultimate tendency of the surrounding magma was to *destroy* the emery, *not to develop it.*

A sharp distinction has been drawn between contact-metamorphism and assimilation, but the two processes actually grade into each other. Assimilation is simply the ultimate of exomorphism and is possible only where the country rock is in contact with the active magma.

CONTACT-METAMORPHISM

"Deuteric" Contact-Metamorphism

In 1930, Gillson and Kania[32] concluded that:

> "The Peekskill emery deposits are contact-metamorphic in origin and were formed by gaseous or liquid emanations from the magma reservoir, which passed upward through the already solid border of the igneous mass, and into the schists, depositing the ore minerals in both the endomorphic and exomorphic zones."

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[29] Morozewicz, J., *Op. cit.*, 1898.

[30] Berkey, C. P., and Rice, M., *Op. cit.*, 1919.

[31] Bowen, N. L., *Op. cit.*, 1922.

[32] Gillson, J. L., and Kania, J. E. A., *Op. cit.*, 1930, p. 526.

The observations on which their conclusions were based may be summarized as follows:

(1) Emery is present only in a post-consolidation endomorphosed rock and exomorphosed schist. It is not in contact with fresh melanorite.

(2) Ore and gangue minerals are contact-metamorphic minerals.

(3) Sequence of mineralization is characteristic of contact-metamorphic processes.

(4) The character and location of the emery deposits, especially within the wall rock, precludes the possibility of its formation by magmatic reaction.

(5) Feldspar of the emery is andesine. Andesinization was a post-consolidation process, yet the formation of the emery followed it.

(6) Quartz and corundum are found in the same thin-section of endomorphosed igneous rock. This would be impossible if the ore were formed by assimilation.

(7) Many minerals present are characteristic of emanations.

(8) The deposits are analogous to contact-metamorphic deposits.

In general, these arguments support a contact-metamorphic theory of origin for the emery. Only the first and fifth arguments favor deposition during that specific stage of magmatic history during which emanations passed from the still-liquid magma chamber through the solidified endomorphosed rock and into the exomorphosed schist. However, the present study has shown that the emery had essentially formed before the endomorphosed rock was entirely solidified. Furthermore, the emery deposits in the endomorphosed rock are engulfed blocks of emerytized metaschist, and not veins. No emery observed by the writer in the igneous rock has been deposited along undoubted veins or channels, by solutions or emanations from the still-liquid magma. Many small emery-bearing xenoliths are present in the later-crystallized norites, as well as in the early solidified endomorphosed rock. This association would not seem possible if ore deposition began only after the margins of the intrusive consolidated.

The writer found no undisputable basis for concluding that the formation of emery followed a post-consolidation andesinization. The process of emery formation, as outlined by Gillson and Kania, must be essentially one of deposition, rather than reaction, for it is difficult to conceive of emanations producing the same end-product by reaction with such different types of rocks as endomorphosed norite and schist. Petrologic studies showed no tendency in the Cortlandt rocks to differentiate toward a highly aluminous residue, especially of deuteric nature. Furthermore, some emery deposits in endomorphosed rock are cut across by dikes of Cortlandt material, as well as by fractures healed with deuteric substances. The latter tend to destroy the emery, rather than to form it, and the sequence of formation indicates that emery was present before pronounced deuteric activity took place.

The theory that the emery was formed as a contact-metamorphic deposit during the stage when final consolidation emanations were passing upward from the magma reservoir through the already solidified endomorphosed rock and schist must be modified.

Hydrothermal Contact-Metamorphism

In connection with his study of corundum and albitite bodies, Larsen[33] made a brief visit to the field and concluded that the Peekskill emery deposits were hydrothermal contact-metamorphic in origin. The hydrothermal stage is later in magmatic history than the stage proposed by Gillson and Kania; hence, the objections previously stated relative to their theory apply in this case. Furthermore, the mineral association of the emery has higher temperature and pressure characteristics than that found even in high-temperature hydrothermal deposits. The only cases of hydrothermal mineral association the writer has seen at Emery Hill are later developments and are not related to the formation of the emery.

POSSIBLE PRE-CORTLANDT DEPOSITION OF EMERY

Certain evidence suggests that the emery may have developed *previous* to the intrusion of the Cortlandt series and that possibility deserves consideration. Favoring this idea is the fact that emery is found as bodies in the metaschist but exists only as xenoliths in the endomorphosed and the later-consolidated Cortlandt series rocks. Furthermore, a continuous aureole of emery does not surround the Cortlandt series at its contacts with the Manhattan schist, but the emery is apparently spasmodically distributed.

The ore has igneous associations. In casting about for some other igneous source, attention falls upon the Peekskill granite[34] as the only possibility near at hand. A brief review of the literature lends support to this suggested source because it reveals that emery deposits elsewhere commonly have granitic sources.

The Naxos and Smyrna deposits are reported to be in crystalline limestones near granite intrusions and are more or less closely associated with granite pegmatites.[35]

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[33] Larsen, E. S., *Op. cit.*, 1928.

[34] The Peekskill granite is considered by Berkey (*Op. cit.*[14], 1908), however, to be the acid extreme of the Cortlandt series because of mutual high soda content. No mutual field relationships have been observed.

The Chester, Massachusetts, deposits are along a narrow belt of foliated amphibolite, lying within sericite schist of Silurian age. They are thought to have been developed chiefly by desilication of a granite pegmatite.[36]

The Whittles, Pittsylvania County, Virginia, deposits are reported to be probably contact-metamorphic, developed as lens-shaped bodies chiefly in schist but to some extent in granite near the schist-granite contact. Field relations show that the emery was pre-pegmatite.[37]

In order to check this possibility, a study was made of the Peekskill granite-Manhattan schist contact. A fair exposure, with a pegmatite dike extending from granite into the schist, crops out on the northeast corner of Millstone Hill, directly east of Emery Hill. However, specimens collected at intervals across the contact showed no development of emery minerals. Exposures in recent road-cuts of the Bronx River Parkway extension, from this vicinity to Jacob's Hill, east of Peekskill, revealed large xenoliths of schist engulfed in a granite resembling the Peekskill granite. These inclusions showed no signs of emery development.

Critical re-examination of the emery deposits shows that they are closely associated with the contacts of the schist and the basic Cortlandt series, even though the emery does not necessarily form a continuous aureole around the intrusive. All known major emery deposits are in pyroxenite areas near contacts with the schist. The association is too evident to be a coincidence. Thus, field evidence fails to support the view that emery was formed previous to intrusion of the Cortlandt series.

Conclusion Concerning Origin

All theories which appear worthy of serious consideration limit the formation of the emery to Cortlandt time. Theories based upon magmatic segregation, absorption, and contact-metamorphism—both early "deuteric" and late hydrothermal—leave several observed facts unexplained. After a description of the conditions under which the emery is found and a discussion of the inadequacy of the theories of origin already proposed, it seems only proper to present a theory of origin which, it is believed, takes into account all the facts observed.

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[35] Papavasiliou, S. A., Die Smirgellagerstätten von Naxos selbst denjengen von Iraklia und Sekinos: *Zeit. Deut. Geol. Ges.*, Bd. **65**, Abh., pp. 1–123, 1914.

[36] Gordon, S. G., Desilicated granitic pegmatites: *Proc. Acad. Nat. Sci., Philadelphia*, vol. **73**, Part I, pp. 185–186, 1921.

[37] Watson, T. L., A contribution to the geology of the Virginia emery deposits: *Economic Geology*, vol. **18**, pp. 53–76, 1923.

Such a theory must satisfy the conclusions and supporting observations outlined below.

(1) The commercial emery deposits at Emery Hill are of two types: (a) concentrations introduced either into the country rock of exomorphosed schist, or into mixed igneous and metamorphic rock; and (b) mineralized xenoliths of exomorphosed schist surrounded by endomorphosed rock.

(2) The emery was formed by contact-metamorphic (pyrometasomatic) action of the basic Cortlandt intrusive on Manhattan schist, because:

(a) The major emery deposits are strictly associated with the Cortlandt intrusives, especially with the early formed pyroxenites.

(b) The emery and associated gangue minerals have contact metamorphic affinities. The former consists of corundum, pleonaste, magnetite, specularite, and ilmenite; the latter include sillimanite, kyanite, staurolite, and cordierite.

(c) The occurrence of emery seems limited to the exomorphosed Manhattan schist. Ore deposits are either concentrations introduced into the country rock of schist, or are mineralized xenoliths of schist that have been engulfed in endomorphosed igneous rock.

(3) Emery was apparently formed or deposited by favorable emanations, liquid or gaseous, released from the intruding magma, as is indicated by collective consideration of the following facts:

(a) In deposits in the exomorphosed schist much of the ore embays and cuts into silicates, showing that it had been introduced.

(b) The emery deposits in exomorphosed schist and mixed rock are close to the contact with igneous rock.

(c) Much of the emery forms bands parallel to the pseudoschistosity of the exomorphosed schist. This structure is noticeable in deposits in the endomorphosed norite, and could not develop by crystallization of aluminous segregations in the magma.

(d) Many xenoliths and contacts of schist do not exhibit much emery mineralization, thereby indicating that mere contact with magma did not cause withdrawal of much emery from it. A concentration of favorable emanations was necessary.

(4) The release of the emery depositing emanations from the Cortlandt magma took place early during intrusion. The emanations, at most, did not travel far in advance of the magma. This is demonstrated by the combined facts that:

(a) Emery deposits in exomorphosed schist and mixed rock are close to the contact with igneous rock.

(b) Emery deposits in igneous rock are mineralized xenoliths engulfed by the advancing magma.

(5) The emery deposits were formed previous to solidification of the endomorphosed rock, because:

(a) The emery is present in the endomorphosed rock only in xenoliths of exomorphosed schist. It also is found in the later consolidated norite as smaller xenoliths, which are oriented with igneous structures, such as schlieren.
(b) No veins of emery were found in the endomorphosed rock.
(c) Endomorphosed rock cuts through some of the emery lenses in emery pits and includes fragments of the intruded emery as fragments in contact breccia.
(d) Emery bodies in the endomorphosed rock are transected by Cortlandt dikes and by cooling shrinkage fractures healed with minerals of deuteric origin.
(e) Deuteric and late-stage consolidation emanations tended to destroy, rather than to develop, emery.

The results of the present study seem to justify the conclusion that the Peekskill emery deposits are contact-metamorphic (pyrometasomatic) in origin, and were formed, essentially, in the Manhattan schist country rock by favorable emanations released from the Cortlandt magma *during* intrusion. This is an earlier stage of "contact-metamorphism" than has been previously suggested. It is believed that the emery developed near the contact and not far ahead of the intruding magma which, as it advanced, engulfed some ore in the form of xenolithic blocks. This theory does not assume that the development of emery ceased the moment xenoliths formed, but it is believed that the mineralization took place early and was not continued to a late magmatic stage, having come to completion by the time the marginal endomorphosed rock had solidified.

The fact that emery does not form a continuous aureole around the contact of the Cortlandt series with the Manhattan schist, but is spasmodic, may be due to (1) the varying concentration of appropriate constituents in the emanations, and (2) unfavorable characteristics of the country rock.

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CRYSTALS OF THE REALGAR TYPE: THE SYMMETRY, UNIT CELL, AND SPACE GROUP OF NITROGEN SULFIDE

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Abstract

An attempt has been made to find other crystalline compounds analogous to the mineral realgar, AsS. The recorded characteristics of NS, and NSe and NTe suggested that these might be realgar-like crystals. Nitrogen sulfide, the only one of this series to have received crystallographic attention, had previously been reported as monoclinic on the basis of a study of surface morphology, and orthorhombic on the basis of an x-ray study, the latter symmetry being made the groundwork for a proposed crystal structure. In the present paper, new and different x-ray results are reported, based upon an equi-inclination Weissenberg study. The correct characteristics are:

Crystal system: monoclinic
Crystal class : $2/m = C_{2h}$
Simplest cell :
$a = 8.78$ Å
$b = 7.14$
$c = 8.64_5$
$\beta = 87°39'$
Formula weights NS per cell: 16
Diffraction symbol : $2/mP2_1/n$
Space group : $P2_1/n$

The general characteristics of this cell are identical with those of the realgar cell, but the cells of the two compounds differ markedly in dimensional aspects. This difference is attributed to the difference in radii of the N and As atoms, and the two compounds are believed to be isostructural. Jaeger and Zanstra's crystal structure proposed for nitrogen sulfide must be incorrect because it is based upon an erroneous symmetry.

Introduction

The unit cell and space group of realgar have already been determined.[1] The large monoclinic cell of this mineral contains 16 formula weights of AsS and has the symmetry of $P2_1/n$, C_{2h}^5. This space-group contains only four specialized equipoints, all inversion centers. Its extremely unfavorable geometry provides 21 distinct, permissible ways of accommodating the 16 As and 16 S atoms at the same time. The simplest available structure requires the determination of 15 parameters, five at a time, while the least simple structure requires the determination of 24 parameters, eight at a time. The crystal structure of realgar can, therefore, hardly be determined by straightforward methods. A search was made accordingly for other compounds likely to have the realgar structural type, in the hope of finding physical, chemical, and diffractive clues to the structural plan.

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[1] Buerger, M. J., The unit cell and space group of realgar: *Am. Mineral.*, vol. **20**, pp. 36–43, 1935.

Realgar stands alone among minerals. It is a member of no recognized mineral group and the analogous antimony and bismuth minerals are unknown. It appears reasonable to expect, however, that other structurally similar compounds exist. The formula of realgar may be generalized to AB, where A is an element of group V B, and B is an element of group VI B of the periodic table. The descriptions of compounds of this class suggest that NS, NSe, and NTe are probably of the realgar type. These are all of non-metallic luster, yellowish to reddish in color, and have low melting points. It is also possible that solid NO is of this type; it is described as a colorless, snow-like solid. Certain other compounds of type AB in question are also known, notably PTe, AsTe, SbTe, BiTe, also BiSe and probably BiS. All of these compounds, however, appear to be of metallic luster and, therefore, not obviously related to realgar. All of them have been prepared by reactions essentially in the molten state, as contrasted with those previously mentioned, which are prepared by precipitation from solution.

The best known of the realgar-like compounds, AB, is nitrogen sulfide, usually assigned the formula N_4S_4 because of its molecular weight in solution.[2,7] This is the only compound of the type other than realgar which has received crystallographic attention.

Crystallographic Status of Nitrogen Sulfide

Nitrogen sulfide has received four previous crystallographic investigations. Nicklès[3] first made some very rough measurements and decided that the crystals were orthorhombic hemimorphic. A very complete investigation was carried out later by Artini,[4] who showed that the crystals were monoclinic, established an orientation and axial elements, and made a study of the twinning which occurs abundantly according to two laws, viz., with $\{\bar{1}01\}$ and also $\{101\}$ as twinning planes (Artini's orientation). Artini worked with crystals purified by fractional crystallization from CS_2. Shortly afterwards, Smith[5] studied some nitrogen sulfide crystals purified by sublimation *in vacuo*. He confirmed Artini's

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[2] Schenck, Rud., Ueber den Schwefelstickstoff: *Ann. der Chemie*, vol. **290**, pp. 171–185, esp. p. 177, 1896.

[3] Nicklès, M. J., Sur la forme cristalline du sulfure d'azote: *Ann. Chim. Phys.*, ser. 3, vol. **32**, pp. 420–421, 1851.

[4] Artini, E., Über die Kristallform des Schwefelstickstoffes, N_4S_4: *Rendic. R. Istit. Lombardo di Sc. e Lett. Mailand*, (2) vol. **37**, pp. 864–869, 1904; *Zeit. Krist.*, (A) vol. **42**, pp. 68–69, 1905.

[5] Smith, G. F. Herbert, On the crystalline form of nitrogen sulphide: *Mineral. Mag.*, vol. **16**, pp. 97–99, 1911.

results, retained his orientation and elements, but obtained slightly different values.

Recently, Jaeger and Zanstra,[6] apparently aware only of Nicklès' early paper, again measured some crystals, this time recrystallized from benzene. They concluded that the crystals were *orthorhombic* and established an axial ratio not to be compared with those of Artini or Smith. Jaeger and Zanstra followed their optical goniometric study with a crystal structure study which included a powder photograph and also 30° (60°?) oscillation photographs for each of the three crystallographic axes selected. These data lead them to assign the crystals to space group V_h^1 (*Pmmm*) upon which they based a complete crystal structure composed of loosely packed N_4S_4 molecules.

In the present paper it will be shown that Jaeger and Zanstra's fundamental groundwork was incorrect and that, therefore, the crystal structure upon which it was based is incorrect.

MATERIAL

The writer is greatly indebted to Mr. Mortimer C. Bloom for the careful preparation of suitable nitrogen sulfide crystals. These were prepared following the procedure of Van Valkenburgh and Bailar.[7] They were recrystallized repeatedly from CS_2 until suitable material was obtained. The final material was crystallized by extremely slow evaporation. In this way the abundant formation of twins was avoided. Earlier crops were largely twinned material of the habit illustrated by Jaeger and Zanstra.[6]

METHOD

The writer has shown[8,9] that the symmetry, crystal system, space lattice type, simplest unit cell, and space group can all be determined by the inspection of several *x*-ray films taken with the equi-inclination Weissenberg method. An especially designed apparatus is used for this purpose.[10] This inspective method has been used throughout the present investigation. Unscreened copper *x*-radiation was furnished by a sharply focussed Hadding tube passing about 10 ma. at 40 kv. half wave rectification.

[6] Jaeger, F. M., and Zanstra, J. E., The crystal structure [sic] of nitrogen-tetrasulphide and tetra-hydro-nitrogentetrasulphide: *Proc. Acad. Sci. Amsterdam*, vol. **34**, pp. 782–807, 1931.

[7] Van Valkenburgh, H. B., and Bailar, John C. Jr., Nitrogen tetrasulfide and nitrogen tetraselenide: *Jour. Am. Chem. Soc.*, vol. **47**, pp. 2134–2137, 1925.

[8] Buerger, M. J., The Weissenberg reciprocal lattice projection and the technique of interpreting Weissenberg photographs: *Zeit. Krist.*, (A) vol. **88**, pp. 356–380, 1934.

[9] Buerger, M. J., The application of plane groups to the interpretation of Weissenberg photographs: *Zeit. Krist.*, (A) vol. **91**, pp. 255–289, 1935.

[10] Buerger, M. J., An apparatus for conveniently taking equi-inclination Weissenberg photographs: *Zeit. Krist.*, (A) vol. **94**, pp. 87–99, 1936.

The data include equi-inclination photographs of 0, 1, 2, and 3 levels for rotations about what has been called the *b* axis, from which data the simplest cell was selected. Similar photographs were also made for the 0, 1, and 2 levels for rotations about the *a* axis of this new cell, and also of the 0 level for a rotation about the *c* axis of this cell. Simple rotation photographs were also incidentally prepared for rotations about each of these axes for the purpose of checking the several axial orientations and identity periods.

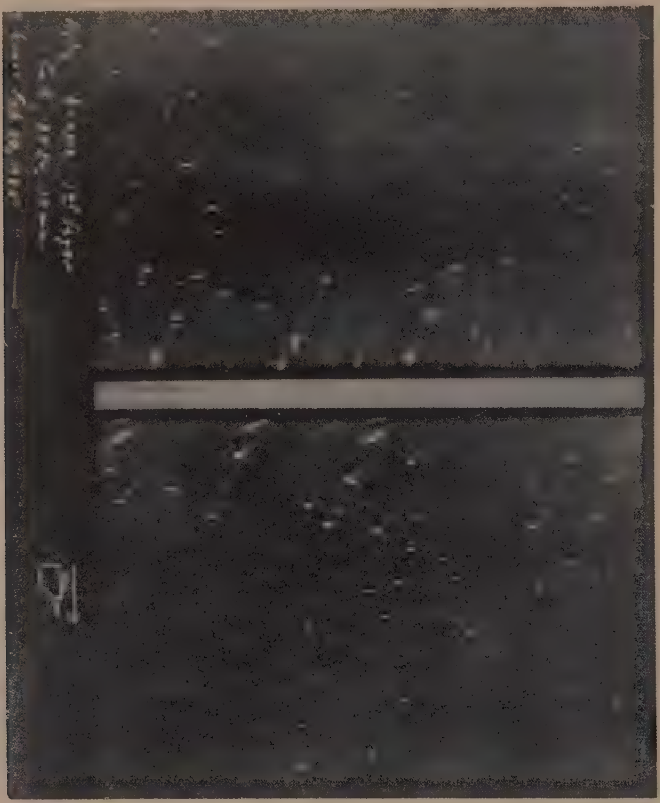

Fig. 1. Equi-inclination Weissenberg photograph from nitrogen sulfide. 1st layer, *b* axis rotation, unscreened copper radiation. The spot intensity distribution is clearly C_2, but the position pseudo-symmetry is close to C_{2l}, with the pseudo-symmetry lines in the positions of the fine slanting lines drawn on the photograph (axes of the simplest reciprocal cell).

SYMMETRY

Although the crystals had an orthorhombic appearance, which was especially enhanced by twinning, those recovered from the final recrystallization had a rather pronounced monoclinic development. Equi-inclination photographs were therefor first prepared for rotations about the suspected 2-fold axis. All such photographs display equi-inclination projections of the plane symmetry[9] C_2, although there is a strong resemblance to C_{2l} for position symmetry alone. These features are plainly visible in Fig. 1. Equi-inclination photographs for rotations about each of the cell axes selected all showed the symmetry C_{2l} for 0 layers and C_l for n layers. This information determines the centrosymmetrical point group to be $2/m$ ($=C_{2h}$). This definitely fixes the crystal system of nitrogen sulfide as monoclinic, although it does not distinguish between the several crystal classes $2/m$, m, and 2. The holohedral nature of the crystal is fixed by space group data noted beyond.

FIG. 2. Equi-inclination Weissenberg photograph from nitrogen sulfide, 2nd layer, *a* axis (Artini's [101] axis) rotation, unscreened copper radiation. The resolution of the spots into increasingly separated pairs along the right hand sloping fine line demonstrates the monoclinic nature of the space lattice type.

SPACE LATTICE TYPE

The plane lattice stacking sequence[9] along the *b* axis is plainly 2, coincident parallelograms. Along the *a* axis the plane lattice type is rectangular and the stacking sequence is 5, side staggered rectangles. That the rectangles are truly staggered, a dimensional and further proof of the monoclinic nature of nitrogen sulfide, is illustrated in Fig. 2, the 2nd level photograph. In this it can be seen that while one line of dome reflections is a central lattice line (the symmetry line), the other prominent line of dome reflections, in a position approximately 90°ω from the first, is a curved, non-central line. This feature is rendered more striking by the presence of a satellitic twin, whose corresponding dome reflections deviate more and more from those of the main crystal near the center line of the film. These data fix the space lattice type as primitive monoclinic, $2/mP$.

UNIT CELL

The *b*-axis rotation, *n* layer films clearly show that the smallest cell results by choosing axes parallel to Artini's[4] $[\bar{1}01]$ and $[101]$ directions. The approximate dimensions of this cell are obtained by the use of the Z scale[8] on the *n* layer photographs. The dimensions are refined by measurements of high θ pinacoid reflections from the zero layer photographs. The reciprocal lattice vectors a^*, c^*, and c^*-a^* form a triangle, one of whose angles is the crystallographic element, β. Accurate measurements of the reflections from (100), (001), and $(\bar{1}01)$, therefore, yield data for the calculation of β to the same degree of accuracy as that of the other cell constants. The complete set of cell constants for nitrogen sulfide calculated from *x*-ray data are:

	absolute	*ratio*
a	8.74 Å	1.224
b	7.14	1.
c	8.64_5	1.211
β		87°39′

If this cell contains 16 formula weights of NS, corresponding with the case of realgar, the density of the crystals may be calculated as:

$$d=\frac{\text{cell mass}}{\text{cell volume}}=2.23_7.$$

The specific gravities measured by various investigators and collected by Mellor[11] are as follows:

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[11] Mellor, J. W., *A comprehensive treatise on inorganic and theoretical chemistry*, vol. VIII, London, p. 625, 1928.

	2.1166	10°C.	A. Michaelis
	2.2	—	S. A. Vosnessensky
	2.22	15°	M. Berthelot and P. Vieille
unsublimed:	2.20	24°	F. P. Burt and F. L. Usher
sublimed:	2.24	24°	

The calculated and observed densities are in excellent agreement, which thoroughly confirms the expectation that the cell contains 16 NS.

In view of the probability that future crystallographic work on nitrogen sulfide will be referred to the orientation established here, all earlier crystallographic elements have been recalculated to this orientation and are collected in Table 1. It will be observed that the new *x*-ray results check all of Artini's values to within 0.1% to 0.2%. Both sets of values were determined on material recrystallized from solution. The deviations of the new results from Smith's values are rather large, but this is to be expected in view of the fact that Smith worked with sublimed crystals.

Table 1

Crystallographic Data for Nitrogen Sulfide, Referred to Simplest Cell Axes

		Artini[4]	Smith[5]	Jaeger and Zanstra[6]		Buerger
		optical	optical	optical	*x*-ray	*x* ray
ratio	*a*	1.2261	1.2319	1.234	1.230	1.224
	b	1.	1.	1.	1.	1.
	c	1.2118	1.2237	1.188	1.175	1.211
	β	87°30′	87°29′ observed 87°22′ calculated			87°39′
absolute	*a*				8.87Å	8.74Å
	b				7.21	7.14
	c				8.47	8.64_5

The transformations involved in the change to the new orientation are as follows:

Artini and Smith		Buerger
b	→	b
$\frac{a}{2}-\frac{c}{2}$	→	a
$\frac{a}{2}+\frac{c}{2}$	→	c
$[101]\wedge[\bar{1}01]$	→	β
$h-l$	→	h
$h+l$	→	l
k	→	k

The crystal forms observed by Artini and Smith thus become:

Artini and Smith		Buerger
(100)	→	(101)
(001)	→	$(\bar{1}01)$
(101)	→	(001)
$(10\bar{1})$	→	(100)
(010)	→	(010)
$(12\bar{1})$	→	(110)
(111)	→	(012)
(110)	→	(111)
(011)	→	$(\bar{1}11)$

The transformation from Jaeger and Zanstra's axes is:

Jaeger and Zanstra		Buerger
a	→	a
b	→	c
c	→	b

SPACE GROUP

Comparison of zero layer with n layer equi-inclination photographs for rotations about the b axis shows[9] that both a and c reciprocal translations are doubled in the zero layer. This indicates that a diagonal glide plane exists normal to the b axis. Comparison of the zero layer with the n layer equi-inclination photographs for rotations about the a axis shows[9] that the reciprocal translation along the [010] line is doubled. This indicates that a 2-fold screw axis exists parallel with the b axis. The diffraction symbol[9] is therefore $2/mP2_1/n$. The space group is consequently uniquely determined as $P2_1/n(=C_{2h}^5)$.

The existence of both glide plane and screw axis requires the existence of a symmetry plane and a 2-fold axis in the point group, consequently the symmetry of nitrogen sulfide is holohedral monoclinic, $2/m=C_{2h}$.

EQUIPOINT COMBINATIONS

The discussion of possible equipoint combinations follows that for realgar exactly.[1]

DISCUSSION

The complete cell data for nitrogen sulfide may now be compared with those of realgar:

	nitrogen sulfide	realgar
a	8.78 Å	9.27 Å
b	7.14	13.50
c	$8.64_5'$	6.56
β	87°39′	73°27′
formula weights AB per cell	16	16
space group	$P2_1/n$	$P2_1/n$

The general characteristics of the crystal, namely, the formula type, the space group and orientation, and the number of formula weights per unit cell, are identical in the two crystals. The specific cell dimensions, however, differ widely. A difference of this sort is to be expected due to the differing radii of the nitrogen and arsenic atoms, 0.70 Å and 1.21 Å, respectively; the volumes of the cells are proportional to the sums of the atomic volumes to within about 10%. It is the opinion of the writer that the two crystals are isostructural.

AN OCCURRENCE OF BARITE IN THE RED BEDS OF COLORADO

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During the summer of 1934, in the course of field studies conducted in South Park, Colorado, by Northwestern University, an interesting deposit of barite was examined. A claim had been staked in 1932 and some 15 pits of various sizes, the deepest about 10 feet, had been dug and a quantity of barite taken out. Further development work was done in the winter of 1934–1935 and a revisit to the locality the following summer permitted a fuller examination of the occurrence.

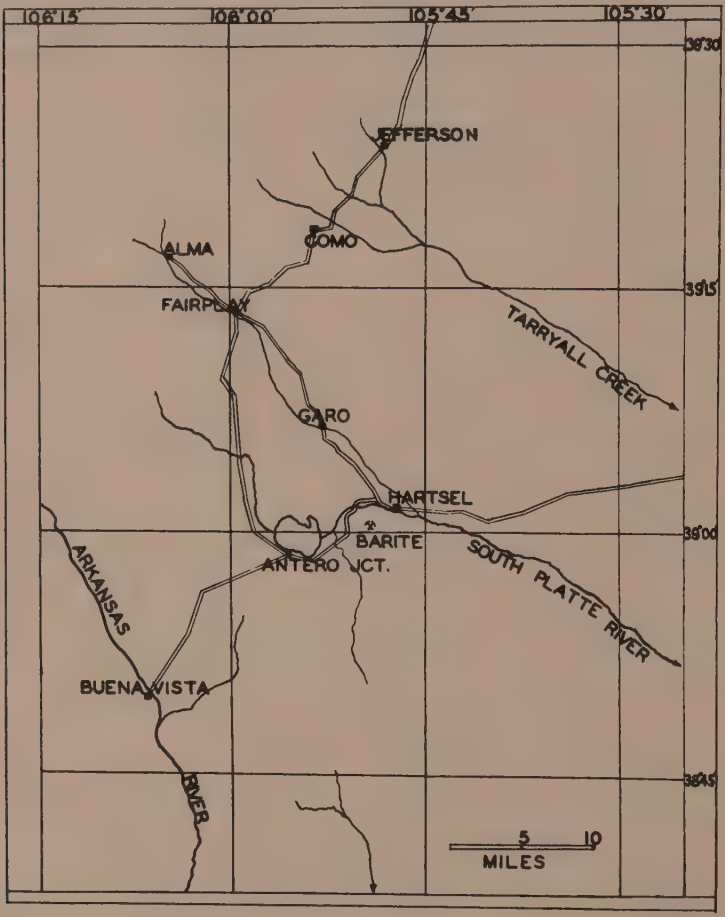

Fig. 1. Index map of South Park, Colorado, showing the location of the barite deposit.

The barite deposit lies about 2 miles southwest of the town of Hartsel in the SE. $\frac{1}{4}$ sec. 18, T. 12 S., R. 75 W. It may be reached by a dirt road which leads southward from the bridge on highway U. S. 40 S, about 2 miles west of Hartsel (Fig. 1).

The stratigraphic horizon of the deposit is a limestone member of the Maroon formation (Permian). Because of rapid thinning of the formation by overlap toward the east, its exact position in the Maroon is unknown, but it is probably in the upper part of the section, and itself overlaps on to the granite about a mile farther east. At the barite locality the limestone dips northeastward from 5–12° and forms the southwestern side of a small structural basin, the northeastern side of which flanks a granite knob south of Hartsel. The surface of the ground is approximately a dip slope and the thickness of the limestone horizon is not determinable, but more than 9 feet is exposed in the deepest of the pits. The red soil and red staining of the limestone suggest that the more typical red shales and sandstones of the Maroon formation formerly lay stratigraphically above this horizon. The limestone is white and fine-grained. Examination of thin sections and insoluble residues discloses a small amount of gypsum. A limestone on the northeast side of the basin which is apparently a nearly equivalent horizon is gypsiferous enough so that it may be scratched readily with the fingernail.

The barite occurs in two ways, (1) as vertical veins from 1 to 2 feet thick, cutting across the beds, and (2) as irregular layers 6 inches to 3 feet thick, roughly parallel to the bedding. The borders of the barite bodies are sharp, but their replacing nature is well shown by a combination of the two types, in which a vein-like mass is enlarged along certain beds through selective replacement (Fig. 2). The barite is a porous aggregate of crystals intermixed with limonite-stained clay, which is probably residual from the weathering and perhaps in part from the replacement of the limestone. In some places there are a few inches of porous brown limonite bordering the under side of the barite layers. Thin coatings of calcium carbonate encrust some of the crystals. No sulphides could be found.

Many masses of the barite have a branching structure, but the ends of the masses, some of which are more than a foot long, show characteristic tabular crystals. Other groups of crystals do not show the branching development (Fig. 3). The well-developed forms are *c* (001), *m* (110), and *d* (102). Measurements of several crystals on the reflecting goniometer showed the presence of the unit pyramid *z* (111) as a very narrow face. Crystals attain a maximum size of more than 1.5 inches in the direction of *c* and 5 inches along the *b* axis. The indices of refraction are $\alpha = 1.635 \pm .001$, $\beta = 1.637 \pm .001$, $\gamma = 1.646 \pm .001$. The specific gravity is 4.45.

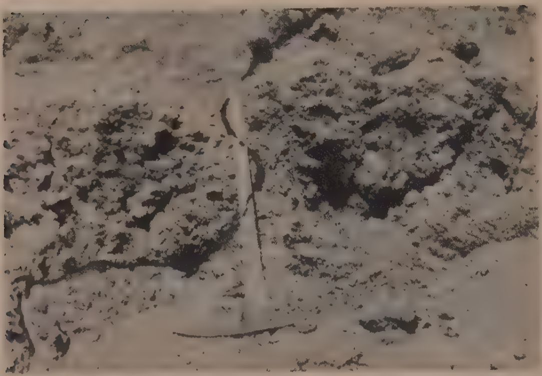

FIG. 2. Barite imbedded in clay cutting irregularly across limestone beds. The barite is below and to the right of the black line.

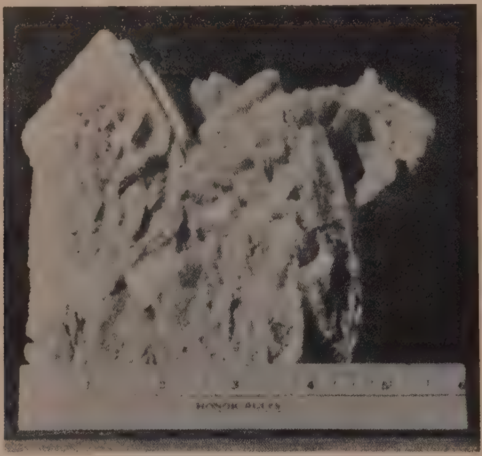

FIG. 3. Group of well terminated barite crystals.

An analysis of the barite is given below. The absence of strontium, though sought for, is noteworthy. A small amount of alkali sulphate may be present.

Analysis of Barite from South Park, Colorado
R. W. Hunt Company, *analysts*

BaO	64.05
CaO	tr.
SrO	none
SO_3	33.71
CO_2	0.22
Loss on ignition (other than CO_2)	0.14
	98.12

The slightly opaque light blue color is a striking feature of the barite. This color is not uniform, but shades off to white in the interior of the branching masses. Doelter[1] found that an irregular blue coloring could be produced from colorless barite by irradiation with radium chloride. In this connection it may be mentioned that there is a locality about eight miles to the north of the barite occurrence where a concentration of radioactive vanadium minerals has been found. This deposit is in a red sandstone of the Maroon, not far above a white limestone member. A similar concentration in the red beds above or below the barite, may have been the cause for the blue color.

The origin of barite has been attributed both to hot rising solutions of magmatic origin and to concentration from surrounding rocks by the action of ground water. Concentration in residual deposits is common, but most of these have been developed from original fissure fillings or replacements. Sources for the barite in South Park might be found either in the sediments of the Maroon formation, or in rising solutions, such as might originate from the magma chamber that furnished Oligocene trachyte in this area.[2] The chloride waters of red beds are known to contain barium in some cases,[3] and percolation of waters through the red sands and shales of the Maroon might have caused the deposition of barite. Gypsum in the limestone would supply sulphate for the precipitation of the barium which had been in solution in waters bearing chlorides and carbonates. The basin-like structure of the Maroon at this locality, as described above, might have served to concentrate downward percolation. At the town of Hartsel, 2 miles to the northeast, is a hot spring. An analysis of the water stated in milligrams per litre[4] is here recalculated to percentage of ions. To supplement this a careful test was made for barium, but no detectable amount was present in either of two tests, and no barite was found associated with this spring or other mineral springs which rise through the Mesozoic beds farther east in the park. At best, evidence based upon the hot springs would be debatable. The present composition of the spring water suggests that though the heat is probably attributable to hot magmatic waters or to hot rock at depths, the waters are entirely meteoric or, if magmatic, are greatly diluted by meteoric waters, a suggestion borne out by the rather high radioactivity of the water. This is what might be expected if water from the red beds, with their known content of radioactive minerals, contributed to the flow of the spring. Any barium present could therefore be attributed to either source.

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[1] Doelter, C., *Handbuch der Mineralchemie*, vol. **4**, pt. 2, pp. 234–235, 1929.

[2] Howland, A. L., Harris, D. V., and Stark, J. T., Bedrock geology of southern South Park (abstract): *Proc. Geol. Soc. Am.*, 1934, p. 84, **1935.**

[3] Jones, F. A., New Mexico mines and minerals, p. 309, Santa Fe, New Mexico, **1904.**

[4] George, R. D., and others, Mineral waters of Colorado: *Colorado Geol. Survey, Bull.* **11,** p. 311, 1920.

Analysis of Hartsel Hot Spring

H. A. Curtis and O. C. Lester, *analysts*

Cl	35.48
SO_4	14.76
CO_3	13.73
Na	27.17
K	1.08
Li	tr.
Ca	4.38
Mg	1.29
Mn	tr.
SiO_2	2.03
$(Fe, Al)_2O_3$	.08
	100.00

Milligrams per litre = 2248.05

Temperature = 56.5°C.

Curies of Ra emanation per litre . . . . . . 15.14×10^{-10}

Permanent activity, grams Ra per litre . . . . . . 0.180×10^{-10}

Concentration of the barite from surrounding sedimentary rocks is here preferred to deposition from rising solutions for the following reasons:

1. A reasonable source of barium is found in the saline waters of the red beds of the Maroon formation.
2. The position of the deposit corresponds with a synclinal structure, such as might control the flow of meteoric waters.
3. A precipitating agent in the form of gypsum is available in the limestone.
4. Sulphides or other minerals common in deposits formed by hypogene solutions and often associated with barite of possible deep seated origin are conspicuously absent.

ON ROSELITE AND THE RULE OF HIGHEST PSEUDO-SYMMETRY

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SUMMARY

Revision of the geometrical and optical crystallography of roselite—$(Ca, Co, Mg)_3$-$As_2O_8 \cdot 2H_2O$ from Schneeberg, Saxony, leads to results that differ in many important respects from the classical data of Schrauf (1874). Roselite proves to be monoclinic, prismatic; $a:b:c = 0.8780:1:0.4398$, $\beta = 100°53'$; forms: $c\{001\}$, $b\{010\}$, $a\{100\}$, $j\{120\}$. $k\{350\}$, $l\{230\}$, $m\{110\}$, $n\{210\}$, $o\{012\}$, $p\{111\}$, $q\{\bar{1}11\}$, $r\{\bar{2}38\}$, $s\{\bar{1}22\}$, $t\{454\}$; cleavage $\{010\}$; twin plane (100). Pale rose crystals show: X (pale rose):$[001] = +0°$ to 1°; Y (paler rose)$=[010]$; Z (palest rose); indices (Na): $nX = 1.694$, $nY = 1.704$, $nZ = 1.719$; positive; $2V = 75°$; $r < v$. Dark rose crystals are zoned; X (deep rose)$=[010]$; Y (pale rose): $[001] = +12°$ to 20°; Z (paler rose); indices (Na): $nX = 1.725$, $nY = 1.728$, $nZ = 1.735$; positive; $2V = 60°$; $r < v$. As now described, roselite is homeomorphous with brandtite—$Ca_2MnAs_2O_8 \cdot 2H_2O$, as described by Aminoff (1919).

Roselite is another case in which the lattice with the highest pseudo-symmetry (pseudo-orthorhombic) is a multiple lattice of the proper crystal lattice. In all such cases the Rule of Highest Pseudo-Symmetry gives unsatisfactory morphological elements and abnormal form symbols.

Pseudo-symmetry is one of the most remarkable facts of crystallography. With axial angles approaching 90° or 60° and axial lengths nearing equality, many crystal species of low real symmetry simulate higher symmetry in their geometrical elements. This metrical[1] pseudo-symmetry of the morphological lattice is typically accompanied by corresponding pseudo-symmetry in the arrangement and development of the forms, in the geometry of the diffraction patterns obtained with *x*-rays, and in the optical behaviour. Furthermore, since planes and axes of pseudo-symmetry are commonly planes and axes of twinning, crystals with pseudo-symmetrical lattices frequently occur in twinned complexes actually possessing the elements of symmetry of the higher system simulated by the homogeneous crystal. By pseudo-symmetry the properties of a crystal may approach those of any higher system. Examples of all the possible cases of pseudo-symmetry are known, even of the extreme case of triclinic crystals that approach the symmetry of the cubic system.

In pseudo-symmetrical crystals the geometrical constants may depart from the simulated higher symmetry by amounts which cannot be overlooked, say one degree or more in axial angle or one per cent or more in axial length. In many cases, however, the departures are much smaller and pseudo-symmetry has been detected and demonstrated only by close study of favourable material. Finally, there are cases in which pseudo-symmetry is justly suspected, but cannot be proved by goniometry since the metrical departure from higher symmetry is less than the probable error of observation.

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[1] The use of "metrical" in this sense was suggested to me in conversation by Professor R. L. Parker, in Zürich.

The fundamental nature of pseudo-symmetry has been recognized by most morphologists, and what may be called the Rule of Highest Pseudo-Symmetry has been widely applied in selecting crystallographic elements. By this rule the lattice with the highest pseudo-symmetry is chosen and oriented in the manner proper to the system approached by the pseudo-symmetrical crystal. Frequently this procedure has led to elements exhibiting true pseudo-symmetry of the species; but in some cases the quality of pseudo-symmetry has been strained, as shown by unnatural form symbols and lack of pseudo-symmetry beyond the metrical pseudo-symmetry of the chosen lattice. Friedel (1904) has discussed many striking cases of the misuse of the principle of pseudo-symmetry in determining crystallographic elements. A further example is provided by roselite, in which the presumed pseudo-symmetry led not only to unnatural form symbols but, as it now appears, to the acceptance of fictitious forms. Furthermore, a re-study shows that a too serious regard to small angular differences has resulted in roselite being placed in the wrong crystal system and provided with a series of twin laws, of which some are certainly imaginary.

SYMMETRY, ELEMENTS, FORMS

Roselite, the rose-red arsenate of lime and cobalt, was named by Lévy (1824), who described the crystals as orthorhombic. This interpretation was accepted until Schrauf (1873, 1874) concluded, from detailed studies, that roselite has pseudo-orthorhombic triclinic elements, and that the crystals are lamellar complexes twinned on as many as five of the six elements of pseudo-symmetry of the chosen lattice. While there is nothing inherently unlikely in this conception, Schrauf's form symbols indicate a false choice of morphological lattice. In his notation the vertical zone contains only one certain form, the eminent cleavage $\{100\}$; such simple forms as $\{010\}$, $\{120\}$, $\{1\bar{2}0\}$, $\{011\}$, $\{0\bar{1}1\}$, $\{101\}$, $\{\bar{1}01\}$, were not observed, although they are entered as hypothetical forms in the angle-table and projection; and the main zone has the improbable symbol series: $\{\bar{1}00\}$, $\{\bar{8}03\}$, $\{\bar{2}01\}$, $\{\bar{4}03\}$, $\{\bar{2}03\}$, $\{203\}$, $\{403\}$, $\{201\}$, $\{803\}$, $\{100\}$.

In a review of Schrauf's work Dr. Laurence LaForge observed these abnormalities and found that by taking Schrauf's (041) as the axial plane (010), retaining Schrauf's (100), (001), (111) with their symbols unchanged, many of the forms received normal symbols while the remainder, if slightly displaced, could be explained by twinning. Although such an interpretation was supported by the appearance of some of Schrauf's figured crystals, a re-investigation was necessary to test and give precision to LaForge's promising supposition and to clear up remaining uncertainties in the morphology and optics of the species.

The crystals studied were detached from two specimens from the Karabacek collection, recently acquired by the Harvard Mineralogical Museum. The specimens come from Schneeberg in Saxony, where roselite has been found on two occasions, first in the Rappold mine, about 1800 or earlier, and again in 1873, in the Daniel mine. One specimen (H.M.M. 93835) carries light-rose crystals whose appearance and association agree exactly with Schrauf's description of the material from the Daniel mine; the other (H.M.M. 93836) has cavities largely filled with deep-rose interlocking crystals corresponding precisely with the Rappold material. Morphologically the two varieties cannot be distinguished, although, as will appear later, they exhibit marked optical differences corresponding to differences in composition and specific gravity, recorded by Schrauf.

The crystals suitable for goniometric study measure less than 1 mm. in greatest dimension. They possess only one highly developed zone, taken as [010] by Schrauf, which contains the single eminent cleavage, $\{100\}$ of Schrauf. The main zone is properly taken as the vertical zone [001], with the cleavage as $\{010\}$; this is the position adopted by Goldschmidt (1897), and considerations of symmetry will show that it is the only reasonable position for the mineral.

The habit is stout prismatic, or rarely thick-tabular after the plane taken as (001), with simple terminations of monoclinic or orthorhombic aspect. Only the smallest crystals have faces giving single sharp reflections; most of the faces give double or multiple reflections in somewhat varying positions, evidently due to the zoned structure of the crystals, later determined optically. These multiple reflections prevent very precise measurement, and they result in a range in the measured angles for the several forms which is wider than usual.

It soon appeared that the morphological lattice of roselite is not pseudo-orthorhombic, as Schrauf believed, but pseudo-monoclinic or truly monoclinic, with a pronounced inclination of the fore-and-aft axis to the vertical. With such a lattice the principal terminal planes, (041), (111), $(\bar{1}11)$, $(\bar{2}2\bar{1})$, $(22\bar{1})$, in Schrauf's notation, become (001), (111), $(1\bar{1}1)$, $(\bar{1}\bar{1}1)$, $(\bar{1}11)$, respectively, perfectly normal and ideally simple symbols. It was also found that the crystals are, almost without exception, twinned by reflection in (100), which causes the pseudo-orthorhombic appearance of most of the terminations. These findings completely confirmed LaForge's supposition based on a consideration of Schrauf's unnatural indices.

A discussion of the best measurements at first led to triclinic elements with the axial angles: $\alpha=90°07\frac{1}{2}'$, $\beta=100°41'$, $\gamma=90°39'$. As far as the measurements showed α might have been exactly 90°; on the other hand, it seemed that γ was certainly not a right angle since (010) was repeatedly observed to be inclined to (010) twinned by reflection in (100) at the considerable average angle of 1°18′ (mean of six measurements). After the morphology was completed on this basis, the preparation of cleavage plates for optical study revealed a remarkable fact: the cleavages (010) and (010) twinned by reflection in (100) gave a perfectly coplanar surface on a twin crystal which showed a definite re-entrant between the corresponding faces. The test was repeated on another twin, with the same result. This showed beyond dispute that (010) and (100) make exactly a right angle; and therefore, since the angle from (010) to (001) is also sensibly 90°, roselite is not triclinic with pseudo-monoclinic symmetry but truly monoclinic. The lack of exact parallelism between the cleavage surface and the external face may be explained by disturbance due to zonal growth, and consequently the slight departure of other faces from exact monoclinic relation is not significant. The similarity of faces on either side of (010), and of upper and lower terminations brought into symmetrical juxtaposition by twinning on (100), show that roselite belongs to the holohedral or prismatic class ($2/m$) of the monoclinic system.

Since roselite proves to be monoclinic, with the cleavage as the symmetry plane, the adopted setting with the main zone vertical and the cleavage as $\{010\}$ is correct. As the five most important terminal planes give simplest indices, the base is properly chosen. In regard to the choice of parametral plane there are two possibilities: either we take the unknown form $\{212\}$ as the unit positive pyramid, giving $n\{110\}$, $m\{120\}$, $l\{130\}$, $k\{3.10.0\}$, $j\{140\}$, as the vertical prism series; or we accept the only important positive pyramid p as $\{111\}$, giving $n\{210\}$, $m\{110\}$, $l\{230\}$, $k\{350\}$, $j\{120\}$ in the vertical zone. Although the author is inclined to believe that the first alternative would give the translation lattice, the morphology seems to demand the second choice, which is adopted.

The mean measured angles on the forms $m\{110\}$, $n\{210\}$, $p\{111\}$, which have faces much superior to those of the remaining forms, give the following projection elements:

$$p_0'=0.5101,\ q_0'=0.4398;\ x_0'=0.1923$$

yielding polar and linear elements which define the morphological lattice of roselite with fair precision:

$$p_0:q_0:r_0=0.5009:0.4319:1;\ \mu=\ 79°07'$$
$$a:b:c=0.8780:1:0.4398;\ \beta=100°53'.$$

Two-circle measurements on ten crystals, all but one of which are twins, are summarized in Table 1. Although the measurements range rather widely, for the reason already given, the mean observed angles agree satisfactorily with the calculated values.

Table 1. Roselite. Measured and Calculated, Two-Circle Angles
$p_0'=0.5101,\ q_0'=0.4398;\ x_0'=0.1923$

Forms	Faces	Measured Range		Measured Mean		Calculated	
		ϕ	ρ	ϕ	ρ	ϕ	ρ
c (001)	10	87°53′–93°23′	10°15′–12°30′	89°34′	11°06′	90°00′	10°53′
b (010)	18	− 0 55 − 1 00	—	− 0 07	90 00	0 00	90 00
a (100)	7	89 18 –90 34	—	89 56	90 00	90 00	90 00
j (120)	17	29 35 –31 44	—	30 53	90 00	30 06½	90 00
**k* (350)	11	34 16 –35 24	—	34 45	90 00	34 50	90 00
l (230)	15	36 50 –38 14	—	37 32	90 00	37 42½	90 00
m (110)	11	48 50 –49 36	—	49 14	90 00	49 14	90 00
n (210)	23	66 21 –67 10	—	66 42	90 00	66 41	90 00
p (111)	24	57 16 –58 25	39 20 –40 04	57 57	39 39	57 57	39 39
q $(\bar{1}11)$	8	−35 04 –37 18	28 00 –28 37	−36 10	28 15	−35 51	28 29
**r* $(\bar{2}38)$	4	20 08 –20 39	10 07 –10 31	20 27	10 15	21 27	10 03
**s* $(\bar{1}22)$	4	—	—	− 7	25	− 8 07	23 57
**t* (454)	4	51 53 –52 18	41 25 –41 44	52 07	41 38	51 57	41 44

* New form.

The forms observed on roselite have the following characteristics:

c{001}: common; usually small, sometimes absent; rarely large producing a thick tabular habit; surface dull giving a weak reflection.

b{010}: cleavage; present as a face on all crystals; generally narrow; surface and reflection fairly good.

a{100}: common; usually narrow, sometimes absent; rarely broad; striated with [001]; surface and reflection fair.

j{120}, *k*{350}, *l*{230}: all common, usually occurring together in a somewhat curved and striated part of the prism zone; the three simple rational symbols represent positions in which the somewhat scattered reflections in this region congregate.

m{110}: common; medium to narrow; surface and reflection very good.

n{210}: present on all crystals; generally broad; surface and reflection very good.

p{111}: present on all crystals; large; surface and reflection very good, sometimes excellent.

$q\{\bar{1}11\}$: fairly common; smaller than p; surface and reflection poor.

$r\{\bar{2}38\}$: four faces on one twin; small, surface poor; reflection weak.

$s\{\bar{1}22\}$: uncommon but large; surface uneven; reflection blurred; symbol determined graphically; the form would not be retained if it did not produce important modification in the appearance of some crystals.

$t\{454\}$: four faces on one twin; narrow; surface fair; reflection weak.

Table 2 is a formal angle-table for the accepted forms of roselite; Fig. 1 gives the corresponding stereographic projection.

TABLE 2. ROSELITE—(Ca, Co, Mg)$_3$As$_2$O$_8$·2H$_2$O
Monoclinic; prismatic—$2/m$
$a:b:c=0.8780:1:0.4398$; $\beta=100°53'$
$p_0:q_0:r_0=0.5009:0.4319:1$; $\mu=79°07'$
$r_2:p_2:q_2=2.3155:1.1599:1$;
$p_0'=0.5101$, $q_0'=0.4398$; $x_0'=0.1923$

Forms	ϕ	ρ	ϕ_2	$\rho_2=B$	C	A
c 001	90°00′	10°53′	79°07′	90°00′	0°00′	79°07′
b 010	0 00	90 00	—	0 00	90 00	90 00
a 100	90 00	90 00	0 00	90 00	79 07	0 00
j 120	30 06½	90 00	0 00	30 06½	84 34	59 53½
k 350	34 50	90 00	0 00	34 50	83 48½	55 10
l 230	37 42½	90 00	0 00	37 42½	83 22	52 17½
m 110	49 14	90 00	0 00	49 14	81 46½	40 46
n 210	66 41	90 00	0 00	66 41	80 01	23 19
o 012	41 10	16 17	79 07	77 49	12 11	79 22
p 111	57 57	39 39	54 55	70 12½	30 53	57 15½
q $\bar{1}11$	−35 51	28 29	107 38	67 15½	35 52	106 13
r $\bar{2}38$	21 27	10 03	86 17½	80 39	11 46	86 20½
s $\bar{1}22$	− 8 07	23 57	93 35½	66 18	27 23	93 17½
t 454	51 57	41 44	54 55	65 46½	33 42½	58 23½

TWINNING

Single crystals of roselite (Fig. 2) are very rare; nearly all the crystals are twinned by reflection in (100) which is also the plane composition surface separating a pair of symmetrical individuals (Figs. 3–6). In most cases the trace of the plane of twinning and composition can be seen on (010) and followed in more or less well-marked re-entrants between the two terminations. Occasionally the twin junction is not visible, but it can always be verified optically in cleavage plates traversing the entire crystal. In one case (Fig. 5) twinning has resulted in a fourling of Roc tourné type, in which the diagonally opposite parts are in parallel position, while adjacent parts in contact on (110) are twinned by reflection in this plane.

The following angles, on a small exceptionally good crystal selected and measured by Professor Palache, show how accurately the terminations are symmetrical about the trace of (100):

	MEASURED		CALCULATED	
	ϕ	ρ	ϕ	ρ
p(111)	58°12′	39°35′	57°57′	39°39′
p(111) twin	− 58 14	39 35	− 57 57	39 39
p(1$\bar{1}$1)	122 02	39 35	122 03	39 39
p(1$\bar{1}$1) twin	−122 02	39 35	−122 03	39 39

In terms of Friedel's excellent development of the treatment of twinning of the French School (1926, pp. 421–483; 245–252) the present twin law is a case of twinning by reticular pseudo-merohedry with index 3 and obliquity 1°16½′. The twin plane (100) (Fig. 7) is a plane of pseudo-symmetry, not of the monoclinic crystal lattice *ABCD*, but of the pseudo-orthorhombic simple multiple lattice *EBFD*—the twin lattice—which can be reflected in (100) with only small deviation at the twin junction (twinning by reticular pseudo-merohedry). The twin lattice restores one third of the total number of lattice points (index 3), and the normal to the twin plane (100) is inclined to the lattice row [301], which is quasi-normal to the twin plane, at 1°16½′ (obliquity). According to the French theory the twin growth occurs in this case because the crystal lattice fortuitously possesses a simple multiple lattice with small index and obliquity.

The twin law described above is equivalent to Schrauf's law (β), which he defined as a rotation of 180° about the normal to $C(001) = a(100)$ of our setting; for Schrauf's remaining laws (α), (γ), (δ), (ϵ), (ζ), (η), we can find no morphological or optical evidence. Of these laws, (α), equivalent to reflection in (010), and (γ), 180° rotation about [010], must be excluded since (010) and [010] are symmetry elements in the prismatic class of the monoclinic system. On the other hand, Schrauf's laws (ζ), 180° rotation about [001], and (η), 180° rotation about [301], and reflection in ($\bar{1}$03), which is not mentioned by Schrauf, are probable twin laws since [001], [301], ($\bar{1}$03), together with (100), are the four elements of pseudo-symmetry of the twin lattice *EBFD* (Fig. 7). Schrauf's remaining laws, (δ), (ϵ), are compound laws involving no new twinning element. The confirmed law and the three probable laws constitute a group of "correspondent twins" (*macles correspondantes* of Friedel) due to the pseudo-symmetry of one and the same lattice.

CORRELATION

The new observations may be compared with those of Schrauf by means of Goldschmidt's two-circle angles computed from Schrauf's data in the position which we have adopted. Table 3 compares our range of measured angles for three typical forms with those of Goldschmidt (1897) after Schrauf. Although the agreement is only tolerable, due to the imperfection of the material and the many peculiar difficulties of the case, the table shows the nature of the correlation between our forms and those of Schrauf. Due to the monoclinic symmetry, each of our forms $\{hk0\}$ is equivalent to two of Schrauf's forms, while the monoclinic symmetry together with the twinning on (100) makes each of our general forms $\{hkl\}$ equivalent to four of Schrauf's forms.

TABLE 3. ROSELITE. COMPARISON OF ANGLES

		Measured Range		Goldschmidt after Schrauf		
		ϕ	ρ		ϕ	ρ
m	110	48°50′– 49°36′	90°00′	ϕ 320	49°05′	90°00′
	$1\bar{1}0$	131 10 –130 24	90 00	*f* $3\bar{2}0$	131 34	90 00
n	210	66 21 – 67 10	90 00	η 310	66 49	90 00
	$2\bar{1}0$	113 39 –112 50	90 00	*e* $3\bar{1}0$	114 09½	90 00
p	111	57 16 – 58 25	39 20 –40°04′	*S* 212	57 04	40 11½
	$1\bar{1}1$	122 44 –121 35	39 20 –40 04	σ $2\bar{1}2$	122 24	40 01½
	111 tw.	– 57 16 – 58 25	39 20 –40 04	*s* $\bar{2}12$	– 54 55	39 28½
	$1\bar{1}1$ tw.	–122 44 –121 35	39 20 –40 04	Σ $\bar{2}\bar{1}2$	–122 54½	38 45½

A full correlation of the form-letters and symbols of Schrauf, Dana, Goldschmidt and the author are given in table 4. The transformation formulas[2] cannot, of course, take account of twinning, and therefore they necessarily give two true symbols, and two false symbols for each (*hkl*) plane in twin position. In Schrauf's column the form letters in parentheses are the hypothetical forms, most of which were accepted by Dana but were properly neglected by Goldschmidt. The last column shows the accepted forms of roselite. Schrauf's hypothetical forms are neglected, none of them having been found in the present study; the rest have been transformed to the new lattice, those provided with letters being accepted, those marked with a dash rejected. Schrauf's *m M* are founded on single doubtful observations; the planes lie in the vicinity of our $s\{\bar{1}22\}$, which is variable in position. Schrauf's $G\,\Gamma\,g\,\gamma$ are accepted as $o\{012\}$. Schrauf's $L\,\Lambda\,l\,\lambda$, giving $\{343\}$ on the new lattice, probably

[2] Derived and written in the convenient manner given by Barker (1930, p. 32).

correspond to our $t\{454\}$. Schrauf's II p, giving $\{\overline{17}.3.3\}$ or $\{511\}$ in twin position, are in either case improbable.

Thus Schrauf's formidable list of thirty-nine forms becomes reduced to ten, to which four new ones are added. The author would hesitate to propose such drastic revision of the work of one of the most skillful of the early observers, were it not for the fact that Schrauf evidently failed to make the critical cleavage test on his twinned crystals, and was unable to obtain the optical effects which would have shown that his edifice of twin laws was partly unreal.

Table 4. Roselite. Correlation of Forms

Schrauf to Peacock: $0\bar{1}4/300/030$
Dana to Peacock: $\bar{1}04/0\bar{3}0/300$
Goldschmidt to Peacock: $40\bar{1}/060/003$

Schrauf 1874	Dana 1892	Goldschmidt 1897, 1922	Peacock 1936
$C\{001\}$	$c\{001\}$	$C\{100\}$	$a\{100\}$
$(Bb)\{010\}$	a$\{100\}$	—	—
$Aa\{100\}$	$b\{010\}$	$A\{010\}$	$b\{010\}$
$(n)\{120\}$	$N\{2\bar{1}0\}$	—	—
$m\{110\}$	$M\{1\bar{1}0\}$	$?m\{012\}$	$-\begin{cases}\bar{1}33\\ 13\bar{3}\end{cases}$
$M\{1\bar{1}0\}$	$m\{110\}$	$?M\{0\bar{1}2\}$	
$(N)\{1\bar{2}0\}$	$n\{210\}$	—	—
$(k)\{011\}$	—	—	—
$(K)\{0\bar{1}1\}$	—	—	—
$d\{041\}$	$d\{401\}$	$d\{104\}$	$c\begin{cases}001\\ 20\bar{3}=00\bar{1}\text{ twin}\end{cases}$
$\Delta\{0\bar{4}1\}$	$\Delta\{\bar{4}01\}$	$\Delta\{\bar{1}04\}$	
$\eta\{203\}$	$\eta\{0\bar{2}3\}$	$\eta\{310\}$	$n\begin{cases}210\\ 2\bar{1}0\end{cases}$
$e\{\bar{2}03\}$	$e\{023\}$	$e\{3\bar{1}0\}$	
$(\chi)\{101\}$	$\chi\{0\bar{1}1\}$	—	—
$(h)\{\bar{1}01\}$	$h\{011\}$	—	—
$\phi\{403\}$	$\phi\{0\bar{4}3\}$	$\phi\{320\}$	$m\begin{cases}110\\ 1\bar{1}0\end{cases}$
$f\{\bar{4}03\}$	$f\{043\}$	$f\{3\bar{2}0\}$	
$v\{201\}$	$v\{0\bar{2}1\}$	$v\{110\}$	$l\begin{cases}230\\ 2\bar{3}0\end{cases}$
$i\{\bar{2}01\}$	$i\{021\}$	$i\{1\bar{1}0\}$	
$\xi\zeta\{803\}$	$\zeta\{0\bar{8}3\}$	$\zeta\{340\}$	$j\begin{cases}120\\ 1\bar{2}0\end{cases}$
$\zeta z\{\bar{8}03\}$	$z\{083\}$	$z\{3\bar{4}0\}$	

TABLE 4. (*Continued*)

Schrauf 1874	Dana 1892	Goldschmidt 1897, 1922	Peacock 1936	
$S\{111\}$	$S\{1\bar{1}1\}$	$S\{212\}$	p	111
$\Sigma\{1\bar{1}1\}$	$\Sigma\{\bar{1}\bar{1}1\}$	$\Sigma\{\bar{2}\bar{1}2\}$		$53\bar{3}=\bar{1}1\bar{1}$ twin
$s\{\bar{1}\bar{1}1\}$	$s\{\bar{1}11\}$	$s\{\bar{2}12\}$		$5\bar{3}\bar{3}=\bar{1}\bar{1}\bar{1}$ twin
$\sigma\{\bar{1}11\}$	$\sigma\{111\}$	$\sigma\{2\bar{1}2\}$		$1\bar{1}1$
$O\{221\}$	$O\{2\bar{2}1\}$	—	q	$133=\bar{1}11$ twin
$\Omega\{2\bar{2}1\}$	$\Omega\{\bar{2}\bar{2}1\}$	$\Omega\{\bar{1}\bar{1}2\}$		$11\bar{1}$
$o\{\bar{2}\bar{2}1\}$	$o\{\bar{2}21\}$	$o\{\bar{1}12\}$		$1\bar{1}\bar{1}$
$\omega\{\bar{2}21\}$	$\omega\{221\}$	—		$1\bar{3}3=\bar{1}\bar{1}1$ twin
$G\{241\}$	$G\{4\bar{2}1\}$	$?G\{114\}$	o	012
$\Gamma\{2\bar{4}1\}$	$\Gamma\{\bar{4}\bar{2}1\}$	—		$43\bar{6}=01\bar{2}$ twin
$g\{\bar{2}\bar{4}1\}$	$g\{\bar{4}21\}$	$g\{\bar{1}14\}$		$4\bar{3}\bar{6}=0\bar{1}\bar{2}$ twin
$\gamma\{\bar{2}41\}$	$\gamma\{421\}$	—		$0\bar{1}2$
$L\{433\}$	$L\{3\bar{4}3\}$	$L\{323\}$	—	343
$\Lambda\{4\bar{3}3\}$	$\Lambda\{\bar{3}\bar{4}3\}$	$\Lambda\{\bar{3}\bar{2}3\}$		$54\bar{3}=\bar{3}4\bar{3}$ twin
$l\{\bar{4}\bar{3}3\}$	$l\{\bar{3}43\}$	—		$5\bar{4}\bar{3}=\bar{3}\bar{4}\bar{3}$ twin
$\lambda\{\bar{4}33\}$	$\lambda\{343\}$	$\lambda\{3\bar{2}3\}$		$3\bar{4}3$
$\Pi\{1\bar{1}4\}$	—	$\Pi\{\bar{8}\bar{1}2\}$	—	$17.3.\bar{3}=\bar{5}1\bar{1}$ twin
$p\{\bar{1}\bar{1}4\}$	—	$p\{\bar{8}12\}$		$17.\bar{3}.\bar{3}=\bar{5}\bar{1}\bar{1}$ twin
—	—	—		$k\{350\}$
—	—	—		$r\{\bar{2}38\}$
—	—	—		$s\{\bar{1}22\}$
—	—	—		$t\{454\}$

OPTICS

The first optical tests, made on small measured crystals of the light rose kind (H.M.M. 93835), tended to confirm Schrauf's conclusion, that the principal optical directions practically coincide with his crystallographic axes, that is with the edges of the pseudo-orthorhombic cell *EBFD* (Fig. 7). Such crystals, single or twinned, lying on any face in the zone [001], extinguish sensibly as a whole parallel to [001]; with [001] in the axis of the microscope they extinguish parallel to the trace of the cleavage {010}. In thin cleavage plates, however, split from measured twins on (100), the trace of the twin plane can be seen, and slightly oblique symmetrical extinction can sometimes be detected, a principal optical direction being inclined to [001] at 0° to 1° in the obtuse axial angle β. Such plates show lively pleochroism in shades of rose-red and fairly strong double refraction. Further study of small crystals, cleavage plates and grains gave the following optical data, the absorption colours being those shown by grains of the order of 0.01 mm. in thickness.[3]

		n(Na)		
X (pale rose)	: [001] = + 0° to 1°	1.694	±0.003	Positive
Y (paler rose)	= [010]	1.704		$2V = 75°$
Z (palest rose)	: [001] = +90° to 91°	1.719		$r<v$

Cleavage plates from the dark rose crystals (H.M.M. 93836), present an appearance which is surprisingly different from that of the light rose material. The dark rose crystals prove to be strongly zoned in shells whose outlines conform to those of the principal forms $\{111\}$, $\{\bar{1}11\}$, and $\{210\}$. Cleavage plates from measured twins on (100) show symmetrical extinction about the trace of the twin plane, a principal optical direction being inclined to [001] at 12° to 20° in the obtuse axial angle β, the angle of extinction increasing in the outer zones. The multiple and somewhat variable reflections given by the bounding planes of many of the crystals may be referred to slight distortion due to an increasing misfit between successive zones that differ in optics and therefore in chemical composition and crystallographic form. The full optical data for the dark rose crystals are as follows:

		n(Na)		
X (deep rose)	= [010]	1.725	±0.003	Positive
Y (pale rose)	: [001] = +12° to 20°	1.728		$2V = 60°$
Z (paler rose)	: [001] = −78° to 70°	1.735		$r<v$

The two kinds of roselite have the same pleochroic formula, the same optical sign, and similar optic axial angle and dispersion; they differ, however, in having noticeably different indices of refraction and entirely different optical orientations. The darker colour and stronger refraction of the dark rose crystals are in keeping with Schrauf's determinations of composition and specific gravity, which showed that the dark crystals from Rappold are richer in cobalt and higher in specific gravity than the light red crystals from the Daniel mine. Possibly we are dealing with distinguishable varieties, and, in the case of the dark crystals, with an isomorphous series; but with insufficient material for adequate analyses this question could not be pursued.

Composition

Schrauf's analyses on minute quantities led him to the formula $Ca_7Mg_2Co_3As_8O_{52}\cdot 10H_2O$ for light rose crystals from Daniel, and

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[3] Mr. Berman kindly made independent optical measurements on the new roselite material, obtaining results which agree with those of the author within the expected limits of error.

$Ca_6Mg_2Co_4As_8O_{52} \cdot 10H_2O$ for dark rose crystals from Rappold. On larger quantities Winker (1877) derived the simpler formula $(Ca, Co, Mg)_3As_2O_8 \cdot 2H_2O$ for roselite. Until further chemical data are available it is proper to follow Dana (1892) and accept Winkler's formula, which is comparable to that of several other natural arsenates and phosphates.

RELATION TO BRANDTITE

When the foregoing work was completed, the description of brandtite —$Ca_2MnAs_2O_8 \cdot 2H_2O$, was examined to see how the new setting of roselite would affect the accepted homeomorphism of the two species. Following Nordenskiöld (in Lindström, 1891), Dana (1892) described brandtite as triclinic, similar in form to roselite, but without geometrical elements. Turning to the later work it was a pleasure to find that the crystallography of brandtite had been revised by Aminoff (1919), who found, as we have in the case of roselite, that brandtite is monoclinic, holohedral, with cleavage {010} and common twin plane (100). The following comparative data show how closely the two species agree in form:

Brandtite—$Ca_2MnAs_2O_8 \cdot 2H_2O$
$a:b:c = 0.8720:1:0.4475$;
$\beta = 99°36\frac{1}{2}'$ (Aminoff, 1919)

Roselite—$(Ca, Co, Mg)_3As_2O_8 \cdot 2H_2O$
$a:b:c = 0.8780:1:0.4398$;
$\beta = 100°53'$ (Peacock, 1936)

Forms in common:	{010}	{100}	{120}	{230}	{110}	{210}	{111}	$\{\bar{1}11\}$
Brandtite................	*A*	*C*	ζ	*v*	ϕ	η	*S*	*R*
Roselite.................	*b*	*a*	*j*	*l*	*m*	*n*	*p*	*q*

Calculated angles:

	ϕ	ρ		ϕ	ρ
$\phi(110)$	49°19′	90°00′	*m*(110)	49°14′	90°00′
S(111)	57 01½	39 25½	*p*(111)	57 57	39 39

Both roselite and brandtite are stout columnar after [001], and both have {010}, {111}, and {210} as the principal forms. It is interesting to note that Aminoff chose what are undoubtedly the proper axes for brandtite even though the base {001} is not known, and that he adopted a plane giving similar parameters to those of roselite, after considering, as we did, the possibility of taking {212} as the unit form. Finally, the optical orientation of brandtite is similar to that of light rose roselite. The homeomorphism of the two species is complete, and there can be little doubt that their ultimate structures must be very similar.

CONCLUSION

The foregoing morphological study has shown that the lattice of roselite with the highest pseudo-symmetry is not the proper crystal lattice of the species, but a multiple lattice; and that the plane of common twinning is a plane of pseudo-symmetry in the multiple lattice but not in the crystal lattice. The same is true in many other species, and in all such cases the Rule of Highest Pseudo-Symmetry leads to improper crystallographic elements. This was clearly recognized by Friedel (1904), who exposed many crystallographic crudities resulting from the ill-considered application of the Rule of Highest Pseudo-Symmetry.[4] Prior to Friedel, the French School regarded all twinning elements as elements of symmetry or pseudo-symmetry of the crystal lattice; this, in effect, made the Rule of Highest Pseudo-Symmetry a theoretical necessity and served to justify the many clearly unnatural settings demanded by this rule. Friedel found the true solution in admitting that elements of twinning are in many cases elements of symmetry or pseudo-symmetry in a multiple lattice of the crystal lattice. Formally, Friedel expressed this significant development of the theory of twinning by adding "twinning by reticular merohedry" and "twinning by reticular pseudo-merohedry" to Mallard's "twinning by merohedry" and "twinning by pseudo-merohedry."

Friedel approached the discussion of twins from the point of view of the Law of Bravais, namely by finding the lattice which gives the best correspondence between the reticular densities of the known planes and their observed relative importance. The proper crystal lattice having been determined in a given case, it is at once evident whether the elements of twinning are elements of symmetry or pseudo-symmetry of the crystal lattice or whether they are elements of symmetry or pseudo-symmetry in a multiple lattice of the crystal lattice; or, in other words, whether the lattice with the highest pseudo-symmetry is the crystal lattice or a multiple lattice of the crystal lattice.

While this method leads, at least in the majority of cases, to the true solution, it is well known that the Law of Bravais is only a first approximation and that, in many actual cases, there is lack of detailed agreement between relative importance of crystal planes and their reticular densities on any lattice that may be chosen. Indeed, there are cases in which the Law of Bravais does not give an unequivocal solution, and there are others in which the law leads to a result which is different from that indicated both by the principle of simplest indices and by the röntgenographically determined translation lattice. Such cases cause one to question the value of the Law of Bravais as a basic guiding principle in determining a crystal lattice.

The writer's experience leads him to the conviction that the proper crystal lattice can be determined from morphological data by simple inspection of the indices of the known forms, without subscribing to the belief in a strict relation between reticular density and form importance. And thus he finds himself in a position similar to that adopted by Ungemach. The details of the procedure whereby the lattice is determined from the indices cannot be enumerated and explained here. In simple cases, like the present one, the widely used principle of simplest indices leads directly to the proper solution.

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[4] I am obliged to Professor J. D. H. Donnay for drawing my attention to Friedel's valuable work on twinning.

Pseudo-symmetry remains a crystallographic fact of fundamental significance, and the search for the lattice with the highest pseudo-symmetry is part of every serious morphological study. But to adopt this lattice as the crystal lattice in every case, at the cost of complicating the indices and forcing a pseudo-symmetry which is not expressed in the form development, is contrary to good crystallographic principles and practice.

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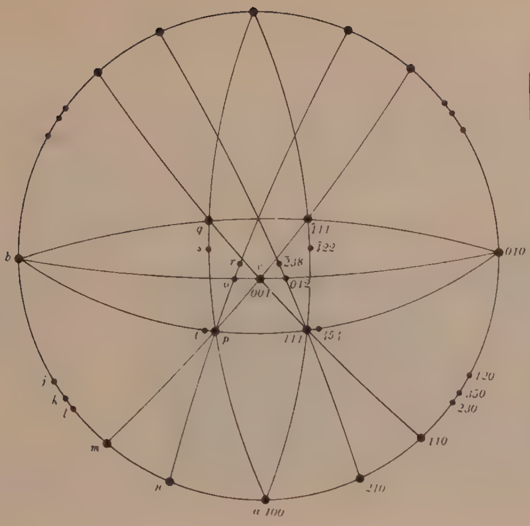

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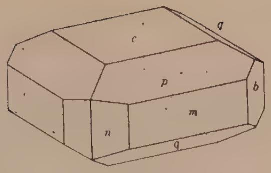

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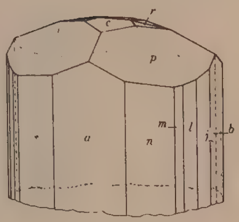

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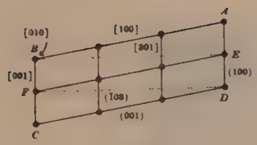

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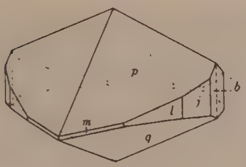

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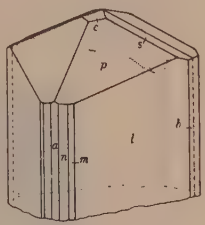

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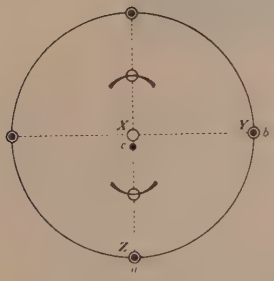

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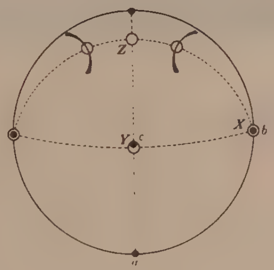

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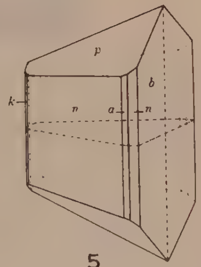

5

FIG. 1. Roselite from Schneeberg, Saxony; stereographic projection of the accepted forms.

FIG. 2. Single crystal, thick tabular after the base.

FIGS. 3, 4, 6. Contact twins on $a(\bar{1}00)$.

FIG. 5 Fourling of "Roc tourné" type.

FIG. 7. Morphological lattice projected on (010), showing six cells of the monoclinic crystal lattice and one cell of the pseudo-orthorhombic twin lattice.

FIG. 8. Optical orientation of the light red crystals.

FIG. 9. Optical orientation of the dark red crystals.

NOTES AND NEWS

"CASTELLATED DOLOMITES" FROM MAJOR COUNTY, OKLAHOMA

C. A. MERRITT, *University of Oklahoma, Norman, Oklahoma.*

Dolomite in pyramidal-like forms was discovered in Major County, Oklahoma, by geologists on a field trip sponsored by the Oklahoma Geological Survey in April 1930. The unusual appearance of these specimens gave rise to the name, "castellated dolomites" and it is by this term that they are now known. They obviously are pseudomorphs as the forms are ones that could not be present on crystals of dolomite.

The "castellated dolomites" are abundant in Sec. 36, T. 22 N., R. 15 W., which locality is a few miles from the town of Sherman. The forms are found in the upper dolomite bed of the Dog Creek shales (Permian). This carbonate layer is dense, gray colored and varies from one to three inches in thickness. Its composition is essentially the same as that of the pyramidal-like forms. These latter are present in the dolomite bed, and as loose forms which have been separated from the rock by weathering.

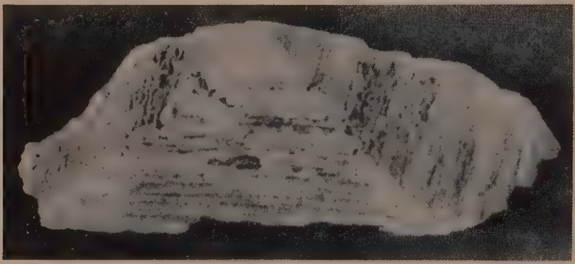

FIG. 1

The "castellated dolomites" vary in size from one-half inch to five inches along an edge. They are gray on fresh surfaces and a brown gray on weathered planes, the latter color being due to a slight iron oxide coating. The forms are of three types, namely, (1) single pyramidal-like forms (Fig. 1); (2) pyramidal forms of the first type but aggregated together in groups of two, three or four with the individuals meeting at a common central point (Fig. 2); and (3) cube-like forms, many of which exhibit hopper-shaped depressions (Fig. 3).

Microscopic studies of the specimens show that they are composed of a mosaic of minute dolomite crystals. Fine quartz and clay are distributed irregularly throughout the dolomite, but also form in thin bands. These bands are more resistant to weathering than the carbonate and therefore produce the laminated appearance so characteristic of these specimens. One small grain of blue tourmaline (elbaite) and a few shreds of chlorite were observed in the thin sections. The dolomite crystals are less than 0.01 mm. in size and the quartz varies from 0.01 to 0.1 mm. The latter mineral is angular to sub-angular in shape.

The interfacial angles vary from 45° to 65° in the pyramidal types and from 80° to 90° in the cube-like forms. This wide variation robs the angles of any value they might have as criterion indicating the character of the original mineral. Apparently the pseudomorphic changes have not operated along precise crystallographic directions.

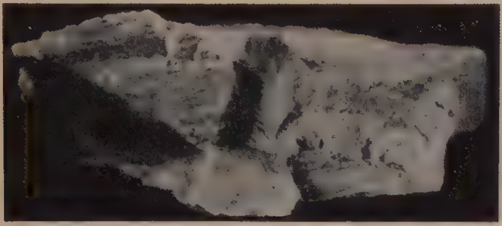

Fig. 2

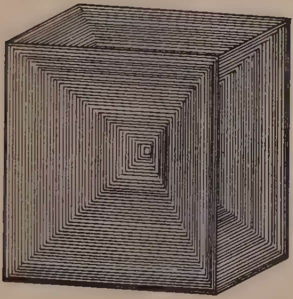

Fig. 3

Chemical analyses of the pyramidal-like forms gave the following results:

	1*	2*
SiO_2	10.60%	9.90%
FeO Fe_2O_3 } as Fe_2O_3	0.93	0.79
Al_2O_3	2.56	2.00
MnO	0.13	0.61
CaO	26.50	27.90
MgO	18.66	17.05
Cl	trace	0.52
Na	trace	0.34
CO_2	41.15	40.50
total	100.53	99.61

* Analyses by Locke of the Oklahoma Geological Survey.

The results of the chemical and microscopic studies suggest that the iron and manganese are present as isomorphous replacements in the dolomite. The silica is chiefly in the form of quartz, but to a minor extent as clayey aluminum silicates whose exact characters were not determined.

The presence of NaCl in some of the specimens and the cube-like forms with hopper depressions indicate that the original mineral was halite. The manner in which the pyramidal-like forms aggregate together (Fig. 2) suggests that these shapes resulted from the filling of the hopper cavities of halite cubes of the type illustrated in Fig. 3. The cube has six hoppers and the filling of these would give rise to six hopper casts all meeting at a common center. By weathering these could be separated into single forms or aggregates of two, three, four or five casts.

The pyramidal-like form is thus considered to be a pseudomorphic cast of one hopper depression of an unusually large halite cube. The dolomite cast may represent the original filling of the hopper cavity or the carbonate may have replaced some other material such as sand and clay which previously had occupied this space. The presence of fine quartz and clay in the specimens lends some support to the second alternative.

The variation in the interfacial angles of the pyramidal types indicates that the filling of the hoppers did not take place along exact crystallographic lines, which is a feature that the writer finds difficulty in explaining. Differences in the shapes of the hopper depressions and consequently in the interfacial angles might result from uneven solution of the halite. However, such solution should produce uneven planes and edges whereas the dolomite casts have clearcut planes and sharp edges. The variations of the interfacial angles of the cubes is likewise a problem.

Another confusing feature is the orientation of the fine bands of quartz and clay which produce the laminated appearance of the forms. If this clastic material was deposited by sedimentary processes in the hopper depressions of halite cubes, the layers so formed should be essentially horizontal, whereas the fine laminae actually are parallel to the bases of the pyramidal casts. The bands are thus in three distinct planes, two vertical and one horizontal and all three approximately at right angles to one another. A tentative explanation is that the halite cubes were being moved and turned by waves or currents while the clastic material was being deposited. If this were the case, first one hopper and then another would be faced upwards in the sea and filled with the settling sediments.

Cubes and hopper-shaped cubes of red sandy shale have been described by Evans[1] as occuring in Sec. 27, T. 24 N., R. 8 W., in Garfield County.

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[1] Evans, O. F., *Oklahoma Academy of Science*, p. 120, **1928.**

This locality is approximately forty-five miles from the one discussed in this paper but the two occurrences have many similarities. Their origins are probably the same, except that in one case the shale pseudomorphic casts were replaced by dolomite and in the other case they were not.

Two other similar forms are in the Oklahoma Geological Survey collections. One is a gray shale from Sec. 24, T. 21 N., R. 15 W., and the other is a pinkish shale from Sec. 34, T. 22 N., R. 1 W. The forms apparently are rather widespread in the Permian of Oklahoma.

CUMMINGTONITE FROM THE BLACK HILLS, SOUTH DAKOTA

Russell G. Wayland, *University of Minnesota, Minneapolis, Minnesota*

Introduction

The mineral cummingtonite occurs abundantly in the Homestake mine, Lead, South Dakota, and likewise to the north of this locality. It also occurs near Rochford, twenty miles southwest of Lead. The cummingtonite is developed in iron-magnesium carbonate horizons in pre-Cambrian schists. It has been described[1] as due to regional metamorphism and to direct reaction between the original iron-magnesium carbonate (sideroplesite) grains and associated grains of sedimentary quartz. However, recent mapping by the geological department of the Homestake Mining Company has shown cummingtonite to be developed only locally and to be associated with original unaltered quartz grains. It is closely related to ore minerals and shows none of the fracturing that might be expected if it had been subjected to regional stresses. In view of this, an alternative hypothesis is that the cummingtonite was formed by the action of hot silica-bearing solutions on sideroplesite. Some of the cummingtonite replaces minerals of known hydrothermal origin.

The greatest metamorphic intensity in the vicinity of Lead occurs about three miles to the northeast of the Homestake mine. Here the cummingtonite seems to be more strongly developed than in the mine. Specimens were collected in regular sequence southward to the mine from this more highly metamorphosed area by Mr. James A. Noble, chief geologist for the Homestake Mining Company. The writer has studied these in order to discover any progressive variations in chemical composition or physical properties which might throw light on the origin of the cummingtonite. This regular variation was not found, however; even the four specimens of cummingtonite taken from near Rochford, where the intensity of regional metamorphism is less than at Lead, differ very little from the average of the Lead cummingtonites.

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[1] Gustafson, J. K., Metamorphism and hydrothermal alteration of the Homestake gold-bearing formation: *Econ. Geology*, vol. **28**, p. 133, 1933.

The writer is especially indebted to Dr. J. W. Gruner, of the University of Minnesota, for invaluable suggestions throughout the study, particularly with regard to the *x*-ray work.

PHYSICAL DATA

The cummingtonite occurs as radiating blades or fibers averaging a half a centimeter in length, but occasionally extending several centimeters. It is brownish or greenish-gray, and sometimes shows a slightly silky luster. Its hardness is 5 to 6, and the cleavage is parallel to (110). Cummingtonite in the form of asbestos-like material around quartz has been found; here its fibers may attain several inches in length and are a translucent yellowish gray.

The specific gravity[2] varies from 3.19 to 3.40, increasing with ferrous iron (Table 1). One specimen, shown by *x*-ray study to be impure, has a specific gravity of only 3.02.

In thin section the mineral is colorless, or faintly grayish brown. No pleochroism was observed by the writer. The extinction angle $Z \wedge c$ is from 17° to 24°. The lower angles belong to specimens higher in ferrous iron.[3] $Y=b$. (Table 1).

The results of determinations of indices by the immersion method are:

Index	*Minimum*	*Maximum*	*Average*
N_α	1.653	1.672	1.662
N_β	1.670	1.694	1.680
N_γ	1.682	1.704	1.693
$N_\gamma - N_\alpha$	0.025	0.040	0.031

The birefringence and refringence increase with ferrous iron. (Table 1).

The optic sign in most specimens is −, but in some, low in iron, it is +. In Table 1 those specimens which are on the border line are listed as ±. The sign of elongation is always +. Dispersion is weak: $r > v$.

The optic angle was determined for each specimen with the aid of a universal stage, and was measured through the fast ray, X. It varies from 70° to 98°, being smaller with higher iron (Table 1).

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[2] Determinations were made with a pycnometer, and, as a precaution, all air was removed from the crushed cummingtonite and the distilled water by boiling under reduced pressure.

[3] Bowen, N. L., and Schairer, J. F., Grünerite from Rockport, Massachusetts, and a series of synthetic fluor-amphiboles: *Am. Mineral.*, vol. **20**, pp. 543–551, 1935. These investigators have found that the curve of extinction angles of their synthetic fluor-grünerites and cummingtonites passes through a maximum at an intermediate composition corresponding to cummingtonite.

TABLE 1. PHYSICAL AND CHEMICAL DATA

Sample	Indices			Biref. $\gamma-\alpha$	Extinc. Angle $Z\wedge c$	Optic Angle (Thru X)	Optic Sign	Sp. Gr. (Obs.)	Per-cent FeO
	α	β	γ						
hf#1	1.662	1.687	1.702	0.040	18°	80°	−	—	34.45
hf#2	1.665	1.679	1.692	0.027	19	84	±	—	26.61
hf#3	1.662	1.680	1.693	0.031	19	98	±	3.19	27.93
hf#4	1.661	1.682	1.697	0.036	18	86	−	3.40	34.45
hf#5	1.661	1.680	1.692	0.031	19	84	−	—	—
hf#6	1.658	1.672	1.683	0.025	20	94	±	—	24.20
hf#7	1.660	1.679	1.689	0.029	24	70	−	—	29.92
hf#8	1.664	1.687	1.697	0.033	17	85?	−	—	33.05
hf#9	1.653	1.670	1.682	0.029	18	82	−	—	—
frf#1	1.657	1.672	1.683	0.026	20	88	±	—	29.65
frf#2	1.658	1.673	1.688	0.030	19	93	±	3.26	31.10
frf#3	1.669	1.684	1.697	0.028	20	92?	±	—	27.20
R.hf#1	1.663	1.679	1.692	0.029	20	87	±	3.02	21.54
R.hf#2	1.665	1.686	1.698	0.033	18	80	−	—	33.72
R.frf#1	1.672	1.694	1.704	0.032	18	80	−	—	30.40
Cummington[a]	1.661	1.677	1.689	0.028	17	84	−	—	32–33
Limit of error	±0.003	±0.004	±0.003	—	±1	±4	—	±0.01	±0.05
Uttersvik[b]	1.6555	1.6717	1.6859	0.0304	15.4	85°20′	−	—	24.13

[a] Smith, L., and Brush, G. J., *Am. Jour. Sci.*, vol. **16**, p. 48, 1853.

[b] Johansson, K., (See footnote[5])

CHEMICAL DATA

The percentages of ferrous oxide are given in Table 1. They vary from 21.54 to 34.45. Some cummingtonites which appear in the hand specimen to be appreciably altered to limonite are found to be only superficially oxidized when analyzed for FeO, or studied by means of *x*-rays. The formula for cummingtonite given by Warren[4] is:

$$(OH)_2(Fe,Mg)_7(Si_4O_{11})_2$$

THE UNIT CELL

The powder method was used for *x*-ray study. Calculation of the unit cell was facilitated by comparison with data obtained by Johansson[5] on cummingtonite from Uttersvik, Sweden, which is higher in manganese than are specimens from the Black Hills. The results for the first four specimens are:

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[4] Warren, B. E., The crystal structure and chemical composition of the monoclinic amphiboles: *Zeit. Krist.*, vol. **72**, p. 513, 1929.

[5] Johansson, K., Vergleichende Untersuchungen an Anthophyllit, Grammatit, und Cummingtonit: *Zeit. Krist.*, vol. **73**, pp. 45–51, 1930.

Specimen	a_0	b_0	c_0
hf#1	9.51 Å	18.22 Å	5.35 Å
hf#2	9.50	18.21	5.33
hf#3	9.53	18.21	5.33
hf#4	9.50	18.23	5.35
Uttersvik	9.55	18.18	5.33

The values of b_0 and c_0 seem to increase slightly with iron. The mean axial ratio is: 0.5224:1:0.2932.

The indices of the lines obtained from powder photographs show the cummingtonite to belong to the monoclinic space group $C_{2h}{}^3$. There are two molecules per unit cell.

THEORETICAL DENSITY

By the relation $V = a_0 b_0 c_0 \sin \beta$, the volumes of the unit cells of specimens hf#3 and hf#4 are found to be 904.31 and 905.84 cubic Å, respectively.

Since complete chemical analyses were not made, it is impossible to compute the exact molecular weights for use in calculating the theoretical densities. However, the FeO percentages and the formula of the theoretical mineral, $(OH)_2(Fe, Mg)_7(Si_4O_{11})_2$, are known, and molecular weights may be calculated which neglect impurities such as manganese, calcium, sodium, and aluminum. The formula of cummingtonite may be thought of as consisting of $H_2O + 7(Fe, Mg)SiO_3 + SiO_2$. The excess silica and the water make up 6.7 and 2.0 per cent, respectively, of the mineral.

Specimen hf#3 contains 27.93 per cent FeO, which is equivalent to 51.25 per cent $FeSiO_3$. There remain 6.7 per cent SiO_2, 2.0 per cent H_2O, and 40.05 per cent $MgSiO_3$. The molecular weight becomes 890. The theoretical density, 3.24, calculated from this agrees well with the observed density of 3.19.

Specimen hf#4, which contains 34.45 per cent FeO, is similar to a cummingtonite specimen analysed by W. J. Sharwood.[6] In his mineral, which contains 34.02 per cent FeO, the ratio of Fe to Si ions is 4.31 to 8. Extrapolating a ratio of 4.5 to 8 for specimen hf#4, we arrive at a molecular weight of 924 and a theoretical density of 3.37. The observed density of specimen hf#4 is 3.40.

Sharwood observed that his analyzed specimen of cummingtonite had a specific gravity of 3.37. If the lattice constant found by the writer for specimen hf#4 is applied to his mineral, a theoretical density of 3.32 is obtained.

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[6] Sharwood, W. J., Analyses of some rocks and minerals from the Homestake Mine, Lead, South Dakota: *Econ. Geology*, vol. 6, p. 747, 1911.

NOMINATIONS FOR OFFICERS OF THE MINERALOGICAL SOCIETY OF AMERICA FOR 1937

The Council has nominated the following for officers of THE MINERALOGICAL SOCIETY OF AMERICA for the year of 1937:

PRESIDENT: N. L. Bowen, Geophysical Laboratory, Washington, D. C.

VICE-PRESIDENT: H. V. Ellsworth, Canada Geological Survey, Ottawa, Canada.

SECRETARY: Paul F. Kerr, Department of Geology and Mineralogy, Columbia University, New York City.

TREASURER: Waldemar T. Schaller, United States Geological Survey, Department of the Interior, Washington, D. C.

EDITOR: Walter F. Hunt, University of Michigan, Ann Arbor, Michigan.

COUNCILOR (1937–1940): A. P. Honess, 113 Frazier Street, State College, Pennsylvania.

The seventeenth annual meeting of the Society will be held December 28–30, at Cincinnati, Ohio. It is planned to publish in the December issue of the *Journal* a preliminary list of titles of papers to be presented before the Society at its annual meeting. In order to appear on the advance program, titles of papers should be in the hands of the Secretary by *November 10*.

A printed program containing abstracts of all papers will be mailed to the membership of the Society prior to the annual meeting. Abstracts for this program, typed in duplicate, should be in the hands of the Secretary by *November 25th*.

Paul F. Kerr, *Secretary*

BOOK REVIEW

A KEY TO PRECIOUS STONES. L. J. Spencer. Crown Octavo, VII+237 pages, 8 plates, and 57 figures. Blackie & Son, Ltd., London and Glasgow, **1936.** Price five shillings.

This book is by the distinguished mineralogist, L. J. Spencer, and is issued in Blackie's Key Series. The volumes in this series aim to serve as lucid, practical, and authoritative guides in the various fields of knowledge, and are sold at the remarkably low price of five shillings.

The KEY TO PRECIOUS STONES is written from the standpoint of the mineralogist in popular language. The scientific aspects of the subject are emphasized, while romance and mystery, so often associated with gems, are kept in the background. The book is divided into two parts, designated as I—GENERAL PRINCIPLES, and II—DESCRIPTIVE PORTION. In Part I the important physical properties, geological occurrences and origin, mining, and the cutting and polishing of gems are adequately discussed. Imitation and artificial gem materials and the nomenclature of gem stones are also considered. Part II contains concise descriptions of properties, occurrences, and uses of those gems which are most commonly used. The book is illustrated with eight full-page plates and fifty-seven line drawings. It is to be regretted that the excellent colored plate which appears on the jacket was not made an integral part of the book.

The author is to be congratulated upon his success in incorporating so much material concerning gems in a text of this size. The volume should prove most helpful to all students and lovers of gems and gem materials, and its very low price should make it easily available.

Edward H. Kraus

PROCEEDINGS OF SOCIETIES

NEW YORK MINERALOGICAL CLUB

In November of 1936, the New York Mineralogical Club will celebrate the 50th anniversary of its existence. The names of many well-known mineralogists of former days may be found in the club's records. Many of its members have made important contributions to the knowledge of mineral localities and to the literature. The anniversary will be marked by a banquet at which a number of speakers will give brief addresses upon the history of the club, its contributions to the science, and the progress made in mineralogy during the half-century that the organization has been in existence.

FREDERICK H. POUGH, *Secretary*

MINERALOGICAL SOCIETY OF GREAT BRITAIN AND IRELAND

MINERALOGICAL SOCIETY, JUNE 25, SIR JOHN S. FLETT, PRESIDENT, IN THE CHAIR

(*1*) *The paragenesis of kyanite—eclogites*. By Professor C. E. TILLEY.

The composition of pyroxenes from eclogites is correlated with that of their associated garnets. The chemistry of kyanite-bearing eclogites and the genetic significance of their contained kyanite is discussed in the light of this relation.

(*2*) *The Tenham* (*Queensland*) *meteoritic shower of 1879* (*or 1869?*). By Dr. L. J. SPENCER.

Very little information can now be gathered about a remarkable shower of meteoric stones that fell in south-west Queensland in 1879 (or 1869?). But a tangible piece of evidence has recently been supplied by the acquisition for the British Museum collection of meteorites of a fine series of 102 complete stones with a total weight of 107¾ lb. This is the best example of a meteoritic shower to be seen in the collection. The stones, ranging in weight from 5245 grams (11½ lb.) to 17.5 grams, were collected over a track extending forty-one miles west to east near Tenham station in the Gregory South district, and they had long remained in private hands. An unpublished chemical analysis, made in 1913 in the Government Chemical Laboratory at Brisbane, shows a striking similarity in composition to the Baroti (India, fell 1910) meteoric stone. Showers of meteoric stones have evidently been produced by the breaking up of a single large mass of friable material in the earth's atmosphere.

(*3*) *Some unusual twin-laws observed in potash-felspars from Goodsprings, Nevada, U. S. A.* By Dr. J. L. E. DRUGMAN.

This locality is unique for fine, sharply defined felspars and the object of this preliminary note is to show the general possibilities of the occurrence for the confirmation of rare or new laws. Besides unusual variants in habit of the Manebach and Baveno laws, examples of other, rarer laws and, possibly, new ones will be shown, e.g. twinning on face $(\bar{1}12)$, on axis $[\bar{1}12]$ and on (110), and on ?$(\bar{3}02)$.